

2011

Agroecological factors impacting stem borer (Lepidoptera: Crambidae) dynamics in Gulf Coast sugarcane and rice

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AGROECOLOGICAL FACTORS IMPACTING STEM BORER (LEPIDOPTERA:
CRAMBIDAE) DYNAMICS IN GULF COAST SUGARCANE AND RICE

A Dissertation
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the formal
requirements for the degree of
Doctor of Philosophy

in

The Department of Entomology

by
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August 2011

ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. T. E. Reagan, for giving me the opportunity to conduct this project. His guidance, support, and high level of expectation helped me grow as a young scientist. I would also like to thank Dr. L. T. Wilson for the time he spent working with me, and for sharing his unique vision and knowledge of agroecosystem research.

I am grateful to my other committee members Drs. D. C. Blouin, M. J. Stout, and E. P. Webster for sharing their expertise in statistics, plant-insect interactions, and rice weed management, respectively. I thank Dr. K. E. Damann for serving as the Dean's representative. I also thank Drs. M. O. Way and A. T. Showler for actively participating in my dissertation project and for letting me use their laboratories and equipment.

Special thanks to Anna Mészáros for everything, including her love, moral support, and entomological expertise 24/7. A Sophie, Daniel, Michel, et Aimée, merci pour tout.

Special thanks to Blake Wilson— friend, colleague, and driver extraordinaire.

I thank Louisiana sugarcane growers Gerald Quebedeaux and Blake Newton, and Texas rice growers Bill Dishman, Jr., John and Jay Jenkins, and Gary and Michael Skalicky for permitting us use of their farmland and for technical assistance. I thank former graduate students Drs. Waseem Akbar, Jiale Lv, and Francis Reay-Jones. I thank Becky Pearson, Mark Nunez, Dr. Lee Tarpley, and Ronnie Porter in Beaumont; Veronica Abrigo and Jaime Cavazos in Weslaco; Jack Vawter and Mike Hiller in Ganado; and Dr. W. H. White and Rita Riggio in Louisiana. I thank Dr. Lowell Urbatsch for identifying numerous grass samples. I also thank Drs. J. A. Davis, L. D. Foil, J. W. Hoy, N. A. Hummel, and S. J. Johnson for participating in the review of selected chapters. I thank student workers Kyle Baker, Jannie Castillo, and Mallory Clarke for their technical assistance.

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ABSTRACT

Diatraea saccharalis (F.) and *Eoreuma loftini* (Dyar) are stem boring pests of sugarcane (*Saccharum* spp.) and rice (*Oryza sativa* L.) crops in the Gulf Coast region. Studies were conducted to determine the role of agroecological factors, including predator disruptions, alternate hosts, and crop phenological conditions, on stem borer populations.

The year after Hurricane Rita storm surge flooded sugarcane in Louisiana, a 71% reduction in the predaceous *Solenopsis invicta* Buren was recorded. Even with a 2.4-fold increase in the number of insecticide applications used for *D. saccharalis* management in flooded fields, growers still incurred higher injury.

In two field experiments, October sampling showed that sugarcane planted in early August harbored 4.7 to 19.0-fold greater *D. saccharalis* infestations than September plantings. Although there is a potential for increased *D. saccharalis* overwintering populations in early plantings, differences in infestations were not recorded during the spring.

Sentinel plant experiments confirmed that a number of non-crop grasses are stem borer hosts. Subsequently, sampling along transects every 6-8 wk compared stem borer infestations in non-crop grasses adjacent to rice fields. While *D. saccharalis* densities were relatively low, *E. loftini* average densities were 0.3 to 5.7 immatures/m² throughout a 2-yr period. A greenhouse study showed that rice is more preferred for *E. loftini* oviposition than the primary non-crop hosts johnsongrass [*Sorghum halepense* (L.) Pers.] and Vasey's grass (*Paspalum urvillei* Steud.). In addition, *E. loftini* larval development duration in degree-days above a threshold temperature is 1.7-fold greater on johnsongrass and Vasey's grass than on rice.

A 2-yr rice study showed that a lower than traditional harvest cutting height (20 vs. 40 cm) reduced *E. loftini* infestations by 70 to 81% whereas *D. saccharalis* infestations were not

changed. Furthermore, rice stubble under favorable conditions represents an overwintering habitat in addition to non-crop hosts.

This research showed that predator disruptions, sugarcane planting dates, non-crop hosts, and rice stubble management impact stem borer populations when they are traditionally left unmanaged. Thus, the evaluation of a stem borer management strategy that targets infestations in late season sugarcane and rice, but also in non-crop hosts, is warranted.

CHAPTER 1: GENERAL INTRODUCTION

The sugarcane borer, *Diatraea saccharalis* (F.), is a pest of sugarcane (hybrids of *Saccharum* spp.), rice (*Oryza sativa* L.), corn (*Zea mays* L.), and sorghum [*Sorghum bicolor* (L.) Moench] (Hensley 1971). Larvae also feed on a wide range of non-crop grasses (Jones and Bradley 1924, Holloway et al. 1928, Box 1956, Bessin and Reagan 1990). *Diatraea saccharalis* was introduced into Louisiana during the 1850s, with sugarcane seed-pieces from South America and the Lesser Antilles, and subsequently spread to the adjacent southern states (Stubbs and Morgan 1902, Holloway et al. 1928). This crambid has traditionally been responsible for most yield losses caused by insects in Louisiana sugarcane (Reagan et al. 1972, Reagan 2001), grown on 167,000 hectares in 2009 (Legendre and Gravois 2010). *Diatraea saccharalis* can also be a serious pest of rice in Louisiana and Texas (Way 2003, Castro et al. 2004), where this crop was grown on 185,000 and 69,000 hectares, respectively, in 2009 (LSU AgCenter 2010a, Texas A&M AgriLife 2010).

The Mexican rice borer, *Eoreuma loftini* (Dyar), belongs to the same Lepidoptera family as *D. saccharalis* (Crambidae) and has a similar crop and weed host range (Johnson 1984, Showler et al. 2011). Introduced from Mexico to south Texas, where it was first reported in 1980 (Johnson and van Leerdaam 1981), *E. loftini* is expanding its range in a northeasterly direction following the Gulf Coast (Reay-Jones et al. 2007c). *Eoreuma loftini* is the most damaging insect pest of sugarcane in the Lower Rio Grande Valley of Texas (LRGV), where it represents more than 95% of stem borer infestations occurring on this crop (Legaspi et al. 1997a, Meagher et al. 1998). *Eoreuma loftini* annual damage to the LRGV sugarcane industry has been estimated close to \$20 million, based on a 20% average level of bored internodes (Legaspi et al. 1999a). This crambid is also becoming an increasing problem on rice in southeast Texas, and is a serious and

imminent threat to the Louisiana sugarcane and rice industries (Reay-Jones et al. 2007c). In December 2008, *E. loftini* was detected for the first time in Louisiana (Hummel et al. 2010), where annual economic losses could be as severe as \$250 million within the next decades (Reay-Jones et al. 2008).

In the Louisiana sugarcane agroecosystem, research on *D. saccharalis* biology and ecology has assisted in developing and implementing integrated pest management (IPM) practices since the 1960s (Hensley 1971). The current management is achieved by elementary cultural practices, conservation of arthropod predators, and properly timed chemical control of economically damaging populations (Posey et al. 2006, Beuzelin et al. 2010a). Cultivar resistance used to be a major tactic in managing *D. saccharalis* in Louisiana (Bessin et al. 1990a, Reagan 2001), but the permanency of *D. saccharalis* management is now threatened by the widespread use of susceptible sugarcane cultivars and subsequent increased insecticide applications (Reay-Jones et al. 2005a). In south Texas sugarcane, the braconid wasp *Cotesia flavipes* (Cameron), introduced from Asia to the New World in the late 1970s, efficiently controls *D. saccharalis* populations (Fuchs et al. 1979b, Meagher et al. 1998). Conversely, *E. loftini* management is more challenging in Texas sugarcane. Chemical control has seldom helped decrease yield losses, and extensive research in classical biological control has not achieved satisfactory outcomes (Meagher et al. 1998, Legaspi et al. 1999b). Additionally, research on sugarcane cultivar resistance to *E. loftini* only began to be investigated in the late 1980s (Pfannenstiel and Meagher 1991). The imminent establishment of *E. loftini* in Louisiana sugarcane encouraged proactive studies integrating cultivar resistance, biorational insecticides, and irrigation (to reduce drought stress) to determine an effective management strategy. Such integration of multiple management

tactics provided a considerably better suppression of damaging *E. loftini* infestations than insecticides alone (Reay-Jones et al. 2003, Reay-Jones et al. 2005d, Reay-Jones et al. 2008).

Diatraea saccharalis and *E. loftini* bionomics in rice and associated management tactics in the southern United States have been little documented due to the sporadic damage caused by *D. saccharalis* and the relatively recent introduction into Texas of *E. loftini*. However, *D. saccharalis* and *E. loftini* injury has been increasing in Texas rice, as well as the average number of insecticide applications (M.O. Way pers. com.). *Diatraea saccharalis* injury has also been increasing in certain rice-growing areas of Louisiana (Castro et al. 2004). In comparison to sugarcane, stem borer chemical control in rice is more efficient probably due to the smaller size of plants that makes larvae more exposed to insecticides (Reay-Jones et al. 2005c). Therefore, farmers rely mainly on insecticides to control these insects. However, economic thresholds have not been established although studies have helped better time insecticide applications (Reay-Jones et al. 2007a). Resistance screenings in Texas also compared relative stem borer injury levels and yield losses in experimental and commercial rice genotypes (Way et al. 2006). Because rice genotypes exhibit various resistance levels, cultivar resistance is anticipated to play an increasing role in stem borer IPM (Way et al. 2006, Reay-Jones et al. 2007b). Conversely, biological control research determined that the use of *C. flavipes* for *D. saccharalis* management in rice would not be a profitable IPM tactic (Lv et al. 2011).

With the introduction of *E. loftini* into Texas, the use of susceptible cultivars, and what seems to be inadequate cultural practices, stem borer pressure has been increasing along the Gulf Coast sugarcane and rice industries (Castro et al. 2004, Reay-Jones et al. 2005c). The currently implemented management practices mainly target economically damaging populations that occur in the summer. However, at times of the year when stem borer populations do not contribute

directly to economic injury, unmanaged infestations may seriously impact pest populations the following year. Therefore, this research project focused on agroecological factors including natural enemy disruptions, sugarcane and rice phenological conditions, and various weed environments during the fall, winter, and spring that were anticipated to affect unmanaged stem borer populations, and as a result pest pressure. First, a study was conducted to quantify the effects of the Hurricane Rita storm surge disruption on the abundance of arthropod predators and the severity of *D. saccharalis* infestations in Louisiana sugarcane (Chapter 3). Sugarcane is traditionally planted from August to October, with the traditional peak in September (Viator et al. 2005b). Producers currently plant both earlier and later in the growing season to facilitate farming operations (Garrison et al. 2000). Thus, field experiments were conducted to determine the effect of sugarcane field phenology associated with earlier and later planting dates on *D. saccharalis* infestations from the summer to the spring (Chapter 4). Because stem borers also infest numerous non-crop grasses, sentinel plant experiments were designed to compare natural infestations on selected non-crop grass species (Chapter 5). These studies showed that non-crop hosts could play a key role in stem borer population build-up. Thus, surveys were conducted to quantify the seasonal abundance of *E. loftini*, *D. saccharalis*, and their non-crop hosts in field margins and surrounding habitats in Texas rice (Chapter 6). Furthermore, to better understand the role of non-crop hosts in rice agroecosystems of the Gulf Coast, a greenhouse study was conducted to determine oviposition preference and larval development duration of *E. loftini* on rice and four primary non-crop hosts at various phenological stages (Chapter 7). Last, to complement sugarcane and non-crop host research, a field study determined the effects of reducing rice main crop harvest cutting height and producing a ratoon crop on late season and overwintering *D. saccharalis* and *E. loftini* infestations (Chapter 8). The ultimate goal of this

work is to provide a foundation for a more comprehensive stem borer management strategy that will include novel tactics that decrease areawide populations by targeting infestations in late season sugarcane and rice, but also in non-crop hosts.

CHAPTER 2: LITERATURE REVIEW

2.1. Taxonomy of *D. saccharalis* and *E. loftini*

The sugarcane borer, *Diatraea saccharalis* (F.), is a stem borer that belongs to the family Crambidae. It was first described by Fabricius in 1794 as *Phalaena saccharalis* (Box 1960), and was subsequently moved to the genera *Diatraea*, *Crambus*, and *Chilo*, before being moved back to the genus *Diatraea* Guiding (Pemberton and Williams 1969). The sugarcane borer was eventually described as *D. saccharalis* by Dyar and Heinrich (1927).

The Mexican rice borer, *Eoreuma loftini* (Dyar), was first reported by Dyar (1917) who described two new distinct species, *Chilo loftini* and *Chilo opinionellus*, bred respectively from sugarcane and wheat in Arizona. Bleszynski (1967) moved *C. loftini* into the genus *Acigona* Hübner, and Klots (1970) showed the two species were conspecifics and moved them into the genus *Eoreuma* Ely. The genus *Eoreuma* belongs to the same tribe as *Diatraea* and *Chilo* species, namely Chiloini (Klots 1970) or Chilonini (Gaskin 1973).

2.2. *Diatraea saccharalis* and *E. loftini* Geographic Distribution

Diatraea saccharalis is widely distributed from the southern United States (Florida to Texas) to Mexico and the West Indies islands, to South America (Colombia, Guyana, Brazil to Argentina, Ecuador, and Peru) (Bleszynski 1969, Pemberton and Williams 1969). This species' first detrimental effects on sugarcane were reported from the West Indies in 1789 (Box 1960). However, the original range of *D. saccharalis* was probably located in tropical South America, from where it expanded throughout the western hemisphere with the adoption of corn and sugarcane production (Box 1951, 1956, Pashley et al. 1990). Although it is not clear how and when *D. saccharalis* was first introduced into the United States, Stubbs and Morgan (1902) and

Holloway et al. (1928) reported that the initial inoculum almost certainly came from sugarcane imported to Louisiana from the West Indies and South America in the 1850s.

Eoreuma loftini occurs in areas of the western coast of Mexico, and in southern Arizona and California (Johnson 1984). Along the Mexican western coast it is an important pest of sugarcane, whereas in Arizona and California it is not considered as a pest, both states not commercially growing sugarcane. In the mid-1970s, *E. loftini* expanded its range to eastern Mexico, and it was first detected in the LRGV of Texas in 1980 (Johnson and van Leerdaam 1981). By 2005, *E. loftini* populations had spread through the Texas rice belt in north and east directions at an average rate of 23 km/yr (Reay-Jones et al. 2007c). In December 2008, *E. loftini* was detected for the first time in southwest Louisiana near the town of Vinton (Hummel et al. 2010).

2.3. *Diatraea saccharalis* and *E. loftini* Host Plants

Diatraea saccharalis larvae are commonly found feeding on sugarcane, rice, corn, and sorghum (Box 1951, 1956, Hensley 1971). *Diatraea saccharalis* has also been reported on wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) in Venezuela (Box 1951). *Eoreuma loftini* cultivated host are the same as for *D. saccharalis* (Dyar 1917, Osborn and Phillips 1946, Johnson 1984).

In addition to crop hosts, Jones and Bradley (1924), Holloway et al. (1928), and Bessin and Reagan (1990) observed that wild grasses including johnsongrass [*Sorghum halepense* (L.) Persoon, reported as *Holcus halepensis*], sudangrass [*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan, reported as *Andropogon sorghum* var. *sudanensis*], para grass [*Urochloa mutica* (Forssk.) T.Q. Nguyen, reported as *Panicum barbinode*], cuscus grass [*Chrysopogon zizanioides* (CL.) Roberty, reported as *Andropogon muricatus*], sprangletop [*Leptochloa panicea* (Retz.) Ohwi, reported as *Leptochloa mucronata*

and *Leptochloa filiformis* (Pers.) Beauv.], dallisgrass (*Paspalum dilatatum* Poir.), hairy crabgrass [*Digitaria sanguinalis* (L.) Scop.], goosegrass [*Eleusine indica* (L.) Gaertn.], jungle rice [*Echinochloa colona* (L.) Link], bearded ryegrass (*Lolium temulentum* L.), savannah panicum [*Phanopyrum gymnocarpon* (Elliott) Nash, reported as *Panicum gymnocarpon*], Vasey's grass (*Paspalum urvillei* Steud., reported as *Paspalum larranagae*), fall panicum (*Panicum dichotomiflorum* Michx.), and bushy bluestem [*Andropogon glomeratus* (Walter) Britton et al.] were hosts of *D. saccharalis* in Louisiana.

Diatraea saccharalis larvae and pupae were also recovered from *Echinochloa polystachya* (Kunth) Hitch., *Hymenachne amplexicaulis* (Rudge) Nees, and *Paspalum fasciculatum* in Peru, and from *Coix lachryma jobi* L., *Panicum grande*, *Oryza latifolia*, *Megathyrsus maximus* B.K. Simon & S.W.L. Jacobs (reported as *Panicum maximum* Jacq.), and *Cyperus ligularis* (family Cyperaceae) in Venezuela (Box 1951, 1956). Quintana-Muñiz and Walker (1970a, 1970b) conducted *D. saccharalis* host preference studies in Puerto Rico and reported oviposition and complete larval development on *Cymbopogon citratus* (DC. ex Nees) Stapf, *Cymbopogon nardus* (L.) Rendle, *Gynerium sagittatum* (Aubl.) Beauv., *Leptochloa scabra* Nees, *Paspalum plicatulum* Michx., *Paspalum secans* Hitchc. & Chase, *Paspalum virgatum* L., *Pennisetum purpureum* Schumach., *Tripsacum dactyloides* (L.) L., and *Tripsacum laxum* Nash.

In addition to crop hosts, Van Zwalunwenburg (1926) stated that *E. loftini* “attacks practically all the grasses large enough to afford it shelter within the stalk.” *Eoreuma loftini* was reported to feed on johnsongrass, sudangrass, *Panicum* grasses, *Echinochloa* grasses, yellow bristle grass [*Setaria pumila* (Poir.) Roem. & Schult. subsp. *pumila* reported as *Setaria lutescens* (Weigel) Hubb.], lemongrass (*C. citratus*), wild millet [*Pennisetum glaucum* (L.) R. Br.], Uruguayan pampas grass [*Cortaderia selloana* (Schult. & Schult. F.) Asch. & Graebn.], and

bermudagrass [*Cynodon dactylon* (L.) Pers.] (Van Zwalunwenburg 1926, Osborn and Phillips 1946, Johnson 1984, Browning et al. 1989). *Eoreuma loftini* was also reported to feed on *Canna* spp. (family Cannaceae) and on bulrush (*Scirpus validus* Vahl, family Cyperaceae) by Osborn and Phillips (1946) and Johnson (1984).

2.4. *Diatraea saccharalis* Life Cycle and Morphology

Diatraea saccharalis life cycle in the Louisiana sugarcane agroecosystem has been studied by entomologists since Morgan (1891). Holloway et al. (1928) provided a comprehensive description of *D. saccharalis* life cycle, habits, and morphology, which are summarized in the following paragraphs.

The duration of the egg stage decreases from 16.5 to 4.6 d for temperatures increasing from 15°C to 32°C under laboratory conditions on artificial diet (King et al. 1975). The cream-colored eggs are flat and oval in shape and ≈ 1.15 mm long by ≈ 0.75 mm wide. They overlap like fish scales and are deposited in clusters (2-100 eggs) on both sides of leaf blades. Larval emergence within a cluster is synchronous. Upon hatching, larvae migrate toward the space between leaf sheaths and stems. Larvae mine the inside of sheaths, and after the second or third molt, tunnel into the stems. Normally, there are five stadia but a few larvae complete a fifth or sixth molt (Roe et al. 1982). For larvae that feed on artificial diet, an increase from 22°C to 30°C decreases mean larval development from 34 to 18 d for stadia one through five; in addition, a temperature of 34°C causes 95% larval mortality (King et al. 1975). Larvae measure 1.5-2 to 25-30 mm in length from stadia one to five, respectively. They are pale yellow-white with a brown head, and during the summer they bear dark brown spots on each body segment whereas the winter form lacks spots.

The within-stem larva cleans and expands the tunnel prior to pupation, leaving only a thin layer of plant tissue for the moth to break through after eclosion. The pupal period averages 7 to 8 d under warm conditions between 26 and 33°C, and approximately 13 d at 22°C (King et al. 1975). The pupa is cylindrical and slender (16-20 mm in length), and yellowish to dark brown in color. The adult is a straw-colored yellowish brown nocturnal moth with wings marked by black dots arranged in an inverted V pattern. Wingspan measures 18-28 mm in males and 27-39 mm in females. The adult stage lasts from 3 to 8 d and oviposition often lasts less than 4 d. Bessin and Reagan (1990) reported that females reared at 27°C from pupae collected in sugarcane fields laid an average of ≈ 700 eggs. Bessin and Reagan (1990) also determined that *D. saccharalis* pupal weight was highly correlated to fecundity.

According to Hensley (1971), four to five generations can potentially occur annually in Louisiana. After pupation during the spring, the first generation emerges in May and June, and attacks young sugarcane tillers that have not formed aboveground internodes. In July and August, the second and third generations injure internodes that contribute most to sugar yields. In September and October, the fourth and fifth generations infest mostly internodes restricted to the top of stalks, which are immature for harvest and contribute little to sugar yields. In agroecosystems where rice is dominant, after adults become active, they breed on various hosts until rice culms reach sufficient size to allow larval feeding (Bowling 1975, Ring et al. 1998). Oviposition can begin on rice as early as May, but economically damaging infestations generally do not occur until August or September. Two to three generations can occur annually in rice fields (Bowling 1975, Ring et al. 1998).

Diatraea saccharalis enters facultative diapause as a large stage larva, and the peak incidence of diapause (63-71% of the field population) under Louisiana conditions occurs

between October and December (Katiyar and Long 1961). Photoperiod and temperature are considered to be the most important factors inducing or terminating diapause. In laboratory experiments, Fuchs et al. (1979a) obtained the highest incidences of diapausing larvae, between 54 and 96%, at 21 and 24°C with 10 and 12 h of light, the lowest temperatures and shortest photophases tested. The lowest incidence occurred for a 14-h photophase regardless of the temperature. Fuchs et al. (1979a) also observed that the proportion of larvae entering diapause under 10 or 12 h photophases could be reduced by a higher temperature of 27°C. Roe et al. (1984) referred to *D. saccharalis* diapause as a delayed metamorphosis triggered by photoperiod, not by adverse conditions. Under laboratory conditions at 21°C, delayed metamorphosis was induced within the first two larval stadia by photophases from 10 to 13 h. Holloway et al. (1928) reported that larvae fed and molted on warm days during the winter, which Katiyar and Long (1961), Fuchs et al. (1979a), and Roe et al. (1984) confirmed. Diapause termination in overwintering field-collected and laboratory-reared larvae was faster under long day and high temperature conditions (Katiyar and Long 1961, Kirst 1973, Fuchs et al. 1979a).

Ingram et al. (1951) asserted that cane trash left in the field after harvest is the most important source of borers that infest new shoots growing the following spring. However, Kirst and Hensley (1974) showed that although leaves and tops of sugarcane stalks left in the field at harvest time are initially heavily infested with small larvae, they decay rapidly and do not serve as habitats for overwintering *D. saccharalis* populations. Also, shoots growing in the fall are not considered as an overwintering habitat. Limited numbers of larvae, however, can use these shoots as a route for entry into seed pieces underground. The main overwintering habitats are underground portions of stubble and newly planted stalks.

Low temperatures were reported to increase overwintering mortality, and although wet winter and spring were believed to adversely affect overwintering *D. saccharalis* populations (Holloway et al. 1928), no correlation between rainfall and borer overwintering survival was found (Kirst and Hensley 1974). The number of larvae surviving the winter 1965-1966 in all crop habitats in a sugarcane field located on a farm in West Baton Rouge Parish was estimated at 307 per hectare (Kirst and Hensley 1974).

2.5. *Eoreuma loftini* Life Cycle and Morphology

Eoreuma loftini eggs are globular and cream-colored. Clusters ≤ 100 eggs are laid in concealed sites, mostly on dry leaves of the lower portion of the sugarcane plant, between 0 and 80 cm above ground (van Leerdam et al. 1984, 1986). In rice, eggs are not as concealed as on sugarcane, and are laid on green and dry leaves, leaf sheaths, and stems (Reay-Jones et al. 2007b). When held at constant temperatures, the egg stage lasts 14 d at 20°C and 5 d at 32°C (van Leerdam 1986). Upon hatching, larvae migrate to green parts of the plant and start to feed on leaf blades and sheaths. Associated with *E. loftini* oviposition behavior, eggs and young larvae are likely less exposed to insecticides and natural enemies than those of *D. saccharalis*. After the second or the third molt, larvae begin to burrow into the stem. When reared in the laboratory, larvae undergo four to six molts. However, the number of larval stadia is affected by sex, being lower in males than in females, with five and six stadia, respectively (van Leerdam 1986). Also, six stadia are observed at 23°C, but five at 29°C. The total larval stage lasts an average of 78 d at 20°C and 21 d at 32°C. The whitish larvae have an orange-brown head capsule and bear four parallel purple-red stripes along their dorsal side. Last instars measure 19-25 mm (Osborn and Phillips 1946, Browning et al. 1989). Larval behavior in sugarcane stems differs from that of *D. saccharalis* because *E. loftini* larvae tunnel vertically, diagonally, and

horizontally. In addition, tunnels where larval feeding and pupation occur are packed with frass. This habit makes larvae and pupae less accessible to natural enemies in comparison to *D. saccharalis*, which cleans its tunnels and pupates in a hollow cavity (Browning et al. 1989, Legaspi et al. 1997a, 1997b).

In laboratory studies, van Leerdam (1986) found that pupal stage durations were 21 d at 20°C and 7 d at 32°C. The pupa has roughly the same shape as in *D. saccharalis*. Nevertheless, *D. saccharalis* pupae bear many tubercles in their abdominal area whereas *E. loftini* pupae bear small tubercles at the posterior of the abdomen (Legaspi et al. 1997b). The adult is a straw-colored moth, somewhat similar to *D. saccharalis*, without any markings but a tiny (< 1 mm) dark spot in the center of each forewing. The adult stage lasts about 7 d.

Temperature influences fecundity and oviposition rates. Fecundity attains 260 eggs at 20°C, a maximum of 400 eggs at 26°C, and declines to \approx 350 eggs at 29 and 32°C. Oviposition rates range from 29 eggs per day at 20°C to 64 eggs at 32°C, and the oviposition peak occurs during the first day of oviposition, usually 2 d after adult eclosion (van Leerdam 1986). As shown for *D. saccharalis*, a linear relationship between fecundity and pupal weight exists (Spurgeon et al. 1995).

Browning et al. (1989) reported a 45 to 50-d length for the duration of a generation under summer conditions in the LRGV. Four to six overlapping generations annually occur in the LRGV sugarcane agroecosystem (Legaspi et al. 1997b), and all stages of *E. loftini* are found in the fields at any time of the year (Johnson 1985, van Leerdam et al. 1986, Meagher et al. 1994, 1996b). However, larvae can enter a facultative diapause during fall and winter months. Browning and Smith (1988) reported that a maximum of nearly 30% of the larval population was in diapause during the fall, and that this proportion increased through the winter. Nevertheless,

the proportion of diapausing larvae was lower during mild winters, and varied considerably among fields. Larval diapause in *E. loftini* is characterized by a slowed activity, stationary molt, and fat body accumulation (Browning and Smith 1988). Both diapausing and non-diapausing larvae feed on warm days during the winter (Browning and Smith 1988). Despite the tropical aboriginal habitat of *E. loftini*, larvae can survive freezing temperatures. Substantial survival occurred when non-diapausing *E. loftini* larvae were incubated at 0°C for 6 d. In addition, 25% *E. loftini* larvae survived 6 d at –5°C, and 10% larvae survived 3 d at –10°C (Browning and Smith 1988).

As for *D. saccharalis*, specific photoperiod and temperature conditions are necessary to initiate diapause. Van Leerdam (1986) obtained the highest incidences of diapausing larvae, between 58 and 79%, at 20 and 23°C with 10 and 12 h of light, the lowest temperatures and photophases tested. In the same study, temperature was the primary factor responsible for the termination of diapause and resumption to a normal development. Cage emergence studies in the LRGV showed a peak of moth emergence in the spring, between late March and early May (Browning and Smith 1988).

2.6. Stem Borer Injury to Cultivated Hosts

Before sugarcane internodes are formed, stem borers feeding on the crown can kill the internal whorl of the plant, which causes a deadheart symptom (Long and Hensley 1972, Browning et al. 1989). However, this type of injury generally does not affect yield, the plant being able to compensate for injury (Hensley et al 1963, Meagher et al. 1994). After internodes have begun to develop, larvae tunneling within the stalk can impair growth, cause stalks to break and lodge, and reduce juice quality (Long and Hensley 1972, Browning et al. 1989). Bored internodes are also more susceptible to fungal infections, such as the red rot disease

(*Colletotrichum falcatum* Went.), that reduce yields and germination of seed-pieces (Ogunwolu et al. 1991).

Larval burrowing injuries may also cause deadhearts in rice. Although the injured culm usually remains green before heading, injury to the vascular tissue can kill the panicle and the developing grain, resulting in whiteheads. When injury occurs during ripening, the maturation of panicles suffers from a lack of uniformity in grain development and increased grain mortality. Mature panicles may also be lost because larval injury to the topmost node can cause the culm to break (Bowling 1975, Browning et al. 1989, Way 2003).

2.7. Host Effect on Stem Borer Behavior and Biology

Painter (1951, 1958) and Kogan and Ortman (1978) considered that plant hosts impact herbivore biology and behavior according to their levels of antibiosis and antixenosis. Antibiosis is the plant host ability to affect herbivore's biology. Typically, a high level of antibiosis can result in herbivore's death, aberrant lifespan, reduction in food reserve and possible unsuccessful subsequent diapause, smaller size, decreased fecundity, and restlessness or abnormal behavior. Antixenosis is the capacity from the plant host to be refractory to herbivore colonization. A high level of antixenosis will deter the herbivore to feed or lay eggs on the host.

Oviposition is of critical importance in Lepidoptera because immatures are relatively immobile and their survival depends much on moth host selection for oviposition (Renwick and Chew 1994). Sosa (1990) compared *D. saccharalis* oviposition among four sugarcane clones, a rice cultivar, a corn cultivar, and a sorghum cultivar. Despite preference variations among sugarcane clones, sugarcane attractiveness was always equal to or higher than that of other hosts. No differences in number of eggs and egg masses per plant were observed between rice, corn, and sorghum. Reay-Jones et al. (2007b) found that sugarcane (cultivars LCP 85-384 and HoCP

85-845) was approximately nine times more attractive for *E. loftini* oviposition than rice (cultivars Cocodrie and XL8) considering the number of egg clusters per plant, and two times more attractive considering egg cluster size.

Quintana-Muñiz and Walker (1970a) released *D. saccharalis* moths in large cages containing sugarcane, rice, corn, sorghum, and 13 non-crop host plants. Plant dissection 20 d later showed that infestations were greatest in corn and sugarcane (20-30% of plants infested), followed by sorghum 14%), *C. citratus* and rice (7-8%) and other weeds (1-6%). Quintana-Muñiz and Walker (1970b) fed *D. saccharalis* third instars with plant host stem portions. Corn (cultivar Mayorbela) was the most suitable host, with 95% of the larvae pupating. *Coix lachryma jobi*, *L. scabra*, *P. virgatum*, and sorghum produced nearly 50% of pupation; *P. plicatulum*, *C. citratus*, and sugarcane \approx 30-35 %; and rice 10%. Mortality reached 90-95% with no pupation when larvae fed on *E. indica* and *E. colona*.

Reagan and Flynn (1986) compared *D. saccharalis* infestations occurring in Louisiana on corn (cultivar Funk's 581), sugarcane (cultivars CP 65-357 and CP 61-37, respectively resistant and susceptible), and sweet sorghum (cultivar Wray). The total number of pupae found during the growing season was the highest in corn, and was equivalent in sweet sorghum and susceptible sugarcane. Moth production per hectare was higher in sorghum (21,800) than in resistant sugarcane (5,500), as was relative survival computed as the ratio of exit holes to bored internodes, which was 0.16 and 0.05, respectively. In addition, the authors found that fecundity was the lowest on sugarcane and the highest on corn. Bessin and Reagan (1990) conducted further experiments with pupae collected on the same sugarcane cultivars, corn (cultivar Meritt), and johnsongrass. Larvae that had fed on the susceptible sugarcane and corn produced females

with a similar fecundity, 717 and 708 eggs per female, respectively. Johnsongrass produced adults with the lowest fecundity.

Host plant species affects herbivore oviposition, development, survival, and fecundity (Thompson 1988, Thomson and Pellmyr 1991). Thus, in an ecosystem where several plant species coexist, herbivore behavior and population build-up on a specific plant species can be affected by the neighboring host plant species. In cultivated ecosystems, the effects of vegetational diversity in terms of arthropod population dynamics are complex and far from following a general pattern (Andow 1991, Norris and Kogan 2005). In each agroecosystem, depending on the cultivated plant, associated herbivores, and vegetation diversity (in plant composition, space, and time), associational resistance or associational susceptibility to the pests may occur (Andow 1991). Vegetational diversity can offer additional shelter for predators, and additional shelter and food for their prey, therefore increasing natural enemy density and subsequently decreasing pest populations (Letourneau 1987, Russell 1989). Conversely, vegetational diversity can offer additional plant hosts and additional host-finding stimuli for the pest; thus increasing pest populations (Karban 1997, Tindall et al. 2004).

Studies conducted in Louisiana showed that corn and sweet sorghum potentially enhance *D. saccharalis* population build-up (Reagan and Flynn 1986). The study of sugarcane fields infested with grasses, broadleaf weeds, or a mixture of both weed types, showed that the presence of non-cultivated plants was associated with a higher abundance and diversity of predators in comparison to weed-free sugarcane fields (Ali and Reagan 1985, Showler et al. 1990, Showler and Reagan 1991). However, Ali and Reagan (1985) reported that the presence of weeds was not associated with differences in *D. saccharalis* injury and moth production. Nevertheless, fields with broadleaf weeds infestations did not suffered yield loss and produced an increase in net

return to the grower. The authors concluded that annual broadleaf weeds, at a subcompetitive level, were beneficial in that they reduced herbicide and cultivation costs while increasing diversity. Showler and Reagan (1991) showed that the presence of annual weeds in sugarcane fields caused at least 25% less injury from *D. saccharalis* compared to weed-free fields. However, the presence of these weeds decreased sugarcane biomass, tiller density, and sugar yields. These losses were partially counterbalanced by decreased cultivation costs.

Diatraea saccharalis and *E. loftini* can use large grasses as hosts (Van Zwaluwenburg 1926, Bessin and Reagan 1990), which may increase pest populations (Norris and Kogan 2005). Infield johnsongrass infestations during the growing season were not significantly correlated with *D. saccharalis* infestations in sugarcane (Ali et al. 1986). The authors, however, encouraged further studies to investigate the possible impact of johnsongrass on *D. saccharalis* injury to sugarcane under heavy infestations. In addition, Bynum et al. (1938) reported that johnsongrass was not an attractive and suitable host during the late summer, and that if cut two or three times a year, the grass was not large enough to provide overwintering *D. saccharalis* larvae with shelter during the winter. These authors concluded that johnsongrass did not represent a source for *D. saccharalis* spring infestations in Louisiana sugarcane. However, sugarcane fields infested with sprangletop (*Leptochloa* spp.) had higher *D. saccharalis* infestations (T. E. Reagan pers. com.). In addition, Tindall (2004) reported an increase in *D. saccharalis* injury to rice when experimental plots were surrounded by Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitch].

2.8. Cultivar Resistance for Stem Borer Management

2.8.1. Sugarcane Resistance to Stem Borers

Since the 1960s, the use of resistant sugarcane cultivars has been an important *D. saccharalis* management tool in Louisiana (Hensley 1971, Bessin et al. 1990a), although it has been

neglected since the mid-1990s with the adoption of high-yielding borer susceptible cultivars (Milligan et al. 1994, Legendre and Gravois 2006). Bessin et al. (1990a) determined that cultivar resistance allowed a 66% decrease in bored internodes, and contributed about 40% to suppressing moth emergence (susceptible CP 61-37 vs. resistant CP 70-330). Furthermore, Bessin and Reagan (1990) showed that resistance affected survival but also the fecundity of the resulting moths. Kyle and Hensley (1970) observed that NCo 310 expressed mainly antibiosis against *D. saccharalis* due to a high mortality among young larvae before tunneling into stalks. Coburn and Hensley (1972) concluded that this type of resistance was mostly mechanically induced by a strong leaf sheath appression. In addition, Martin et al. (1975) found that the percentage of internodes penetrated by *D. saccharalis* larvae was negatively correlated ($r = -0.97$) with internode hardness in eight sugarcane cultivars.

Diatraea saccharalis moths have not shown significant ovipositional preferences among commercially grown sugarcane cultivars (Kyle and Hensley 1970, Coburn and Hensley 1972, Fuchs and Harding 1978). However, Sosa (1990) showed that female moths laid 60% less eggs on a pubescent sugarcane genotype in comparison to genotypes with glabrous leaves. In addition, pubescence delayed the migration of first instars towards the base of the leaf, likely increasing larval mortality (Sosa 1988). Bessin et al. (1991) estimated the build-up of *D. saccharalis* populations as impacted by cultivars with different levels of resistance on an areawide basis. The results of this research suggest that if *D. saccharalis* susceptible cultivars are dispersed among cultivars with better resistance, their influence on *D. saccharalis* populations might be reduced.

Research on sugarcane cultivar resistance to *E. loftini* was initiated in the late 1980s in the LRGV (Meagher et al. 1996a). The first breeding evaluations showed that cultivar CP 70-321 sustained less bored internodes than cultivars CP 65-357 and NCo 310 (Pfannenstiel and

Meagher 1991). Although Meagher et al. (1993) and Legaspi et al. (1999a) confirmed that *E. loftini* injured CP 70-321 less than NCo 310, a 5-yr study showed that this was the case in only 28% of the comparisons (Meagher et al. 1996a). The percent of bored internodes is positively correlated with yield losses; however, *E. loftini* injury impacted yields more severely in CP 70-321 than in NCo 310 (Legaspi et al. 1999a). Reay-Jones et al. (2003), using bored internodes and moth exit holes, observed no significant differences between these two cultivars grown in the LRGV. In this 2-yr study, Louisiana cultivars HoCP 91-555 and LCP 85-384 were the most susceptible to *E. loftini*. HoCP 85-845, which is considered to be *D. saccharalis* resistant, had a level of resistance equivalent to that of NCo 310 (Reay-Jones et al. 2003). Sugarcane cultivars NCo 310, HoCP 85-845, LCP 85-384, and HoCP 91-555 had comparable levels of resistance to both stem borer species (Reay-Jones et al. 2003). These results suggest that some resistance mechanisms similarly affect the two stem borers. The different oviposition behavior in *D. saccharalis* and *E. loftini*, however, may cause differences in cultivar resistance levels.

Oviposition preference studies showed that HoCP 85-845 was 37% less attractive for *E. loftini* oviposition than LCP 85-384 based on egg cluster size (Reay-Jones et al. 2007b). However, Meagher et al. (1996a) did not find differences in oviposition preference among genotypes of the Texas breeding program. Larval antibiosis is expressed in certain sugarcane genotypes (increased development time and decreased pupal weight) but the source of this resistance has not been identified (Meagher et al. 1996a).

Genetically engineered clones expressing snowdrop lectin (*Galanthus nivalis* agglutinin) in order to confer resistance to *E. loftini* have been evaluated. *Eoreuma loftini* suffered decreased larval survival, percentage of adult emergence, and fecundity when fed with transgenic sugarcane (Sétamou et al. 2002b). Conversely, *D. saccharalis* showed no deleterious effects

(Sétamou et al. 2002a). In addition to the antibiotic effects of transgenic sugarcane, Bernal and Sétamou (2003) showed that both *D. saccharalis* and *E. loftini* preferred laying eggs on a conventional cultivar in comparison to the corresponding genetically engineered near-isogenic line.

2.8.2. Rice Resistance to Stem Borers

In Asia, where rice production relies less on insecticides than in the United States, numerous studies have been conducted on rice resistance to stem borer species that are ecologically and taxonomically close to *D. saccharalis* and *E. loftini* (Chaudhary et al. 1984). Morphological characters such as plant height, culm diameter, and length and width of the flag leaf have been positively correlated with the percentage of infested tillers by the Asiatic striped rice borer, *Chilo suppressalis* (Walker) (Patanakamjorn and Pathak 1967). In addition, tight internode-wrapping leaf sheaths (Patanakamjorn and Pathak 1967) and thick layers of sclerenchymatous or lignified tissues under the epidermis (Chaudhary et al. 1984) have been associated with decreased susceptibility of rice to Asian stem borers.

Douglas and Ingram (1942) observed that *D. saccharalis* and *C. plejadellus* were more abundant in rice plants with larger culms. Oliver and Gifford (1975) reported that both borer species' larval growth and development varied among seven rice genotypes tested for the Louisiana breeding program. In addition, larval response to a given genotype was generally similar in both borer species. More recently, Way et al. (2006) conducted a 4-yr study in Texas on rice yield loss as affected by genotype, and *D. saccharalis* and *E. loftini* injury level as measured by the number of whiteheads per m². Priscilla was the most susceptible cultivar with the highest injury levels in the main crop and the greatest yield losses over 3 yr. Despite varying levels of susceptibility among the years, Cocodrie was considered moderately susceptible in

comparison to hybrid lines, which showed injury and yield losses lower than in other cultivars. The hybrid XL8, however, is more attractive for *E. loftini* oviposition than Cocodrie (Reay-Jones et al. 2007b). Although oviposition preference is not known for *D. saccharalis*, Way et al. (2006) suggested that cultivars such as XL8 could act as sinks for *E. loftini* populations and decrease stem borer areawide infestations. In Lv et al. (2008), *D. saccharalis* injury levels in three cultivars (Cocodrie, Francis, and Jefferson) were comparable. However, compensatory responses to injury, manifested by the production of additional reproductive tillers and larger panicles, differed among these three cultivars.

2.9. Cultural Control of Stem Borers

2.9.1. Cultural Control in Sugarcane

To reduce the number of overwintering larvae, stubble in fallow fields should be plowed out as quickly as possible (LSU AgCenter 2010b). Planting stem borer-free sugarcane seed pieces is also an elementary recommended stem borer management tactic (Browning et al. 1989, LSU AgCenter 2010b). Planting and harvesting dates cause various sugarcane phenological conditions potentially influencing stem borer population dynamics. Fields planted in August show increased *D. saccharalis* infestations (Charpentier and Mathes 1969). Viator et al. (2005b) determined the effect of August, September, and October planting dates on the yield of five sugarcane cultivars in Louisiana. Plant cane sugar yields for cultivar LCP 85-384 were not affected by planting date, while for HoCP 85-845 and CP 70-321, sugar yields were higher for the August planting. *Diatraea saccharalis* infestations and injury were not recorded.

Weed management and resulting weed communities in the sugarcane agroecosystem can influence *D. saccharalis* infestations (Chapter 2.7). Although broadleaf weeds can decrease *D. saccharalis* injury in sugarcane (Showler et al. 1990), the role of large grasses as alternate hosts

when growing in the field or in non-crop habitats is poorly understood (Bynum et al. 1938, Ali et al. 1986).

Because corn and sorghum potentially increase *D. saccharalis* populations when grown in sugarcane areas (Reagan and Flynn 1986), farmers are recommended to grow these two crops as far as possible from sugarcane fields (LSU AgCenter 2010b). Modeling areawide population dynamics of *D. saccharalis* on different sugarcane cultivars, Bessin et al. (1991) suggested that the size and spatial arrangement of areas cultivated with the same cultivar were important in population build-up. Thus, to a larger extent, the arrangement in space of hosts with varying levels of suitability for stem borers impacts population build-up on an areawide basis.

The cultural practices discussed above, although mainly studied for *D. saccharalis* control, likely affect *E. loftini* populations in a similar way. Irrigation has been demonstrated to be a key practice in managing *E. loftini* infestations in sugarcane. Irrigation, in reducing sugarcane water deficit stress, reduced the probability of a bored internode by 60% in a 2-yr field experiment (Reay-Jones et al. 2005d). Drought stressed sugarcane plants have higher levels of several free amino acids and more dry leaves (Reay-Jones et al. 2005d, Reay-Jones et al. 2007b), which enhances plant suitability for oviposition and larval development (Showler and Castro 2010a).

2.9.2. Cultural Control in Rice

Rice fields that are planted early can produce a main crop and a ratoon crop. Way and Espino (2010) showed that the heaviest stem borer infestations occurred in the main crop of later planted rice and in the ratoon crop from the early planted rice. After harvest, main crop stubble or ratoon stubble is left in the field over the winter. Management practices such as heavy pasturing of stubble, and fall plowing or winter flooding of fields may help reduce overwintering stem borer

populations (Way and Espino 2010). However, the impact of such practices has not been quantified.

Observations in the Texas rice belt of *D. saccharalis* and *E. loftini* adults during periods of the year when rice plants are either absent from the field or not sufficiently large to allow larval feeding led to the conclusion that stem borers breed significantly on alternate hosts (Bowling 1975, Ring et al. 1998). Weed management in rice field is typically very good (Kendig et al. 2003); however, unmanaged weed hosts surrounding the fields may be important sources of stem borers.

2.10. Biological Control

The introduction of two larval parasitoids, *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) and *Lixophaga diatraeae* (Townsend) (Diptera: Tachinidae), helped reduce *D. saccharalis* injury to sub-economic levels in Barbados sugarcane (Alam 1980). In addition, the successful use of *C. flavipes* to control *D. saccharalis* in sugarcane has been reported in Brazil (Macedo et al. 1984) and in the LRGV (Meagher et al. 1998). In the Louisiana sugarcane agroecosystem, attempts at biological control of *D. saccharalis* have been less successful. Although wasps in the genus *Trichogramma* are found, they do not decrease *D. saccharalis* populations to levels below the economic threshold. Similarly, *L. diatraeae* and *Alabagrus stigma* Brullé (Hymenoptera: Braconidae) have become established but represent a minimal contribution to *D. saccharalis* control (White and Reagan 1999). Attempts at using *C. flavipes* to control *D. saccharalis* are even less encouraging, with establishment failing after more than 15 releases (White et al. 2004).

The current biological control of *D. saccharalis* in Louisiana relies on a complex of predaceous arthropods (Negm and Hensley 1969, Reagan 1986). Studies showed that

insecticides applied to control the red imported fire ant, *Solenopsis invicta* Buren, increased *D. saccharalis* infestations by affecting populations of naturally occurring predators (Hensley et al. 1961). Negm and Hensley (1967, 1969) confirmed these observations by assessing the relative importance of specific predators using correlation data between number of predators and crop injury. In these studies, spiders and ants appeared to be the most important natural enemies feeding on *D. saccharalis* eggs and larvae. Additional predators belonging to the taxa Carabidae (ground and tiger beetles), Elateridae (click beetles), and Dermaptera (earwigs) have also been cited as important *D. saccharalis* predators in Louisiana. Species of Staphylinidae (rove beetles), are also considered as important components of the arthropod complex in the Louisiana sugarcane agroecosystem (Negm and Hensley 1967, 1969). Although the relative importance of each group of predators may vary with the time of the year, population density, location, and crop year, several studies have shown that *S. invicta* is the dominant predator of *D. saccharalis* in Louisiana sugarcane (Reagan et al. 1972, Ali and Reagan 1985, Bessin et al. 1990a). A reduction of 18% in *D. saccharalis* injury was attributed to *S. invicta* predation in a replicated field study (Bessin et al. 1990a).

Rice production in Gulf Coast areas relies essentially on the use of broad-spectrum insecticides to control two key pests, the rice water weevil and rice stink bug, *Lissorhoptrus oryzophilus* Kuschel and *Obealus pugnax* (F.), respectively. In addition, both the annual nature and flooded environment of this crop make the agroecosystem unstable, hindering the establishment and growth of predator and parasitoid populations. These three attributes challenge the effectiveness of biological control programs for *D. saccharalis* in Louisiana and Texas rice. However, *Trichogramma* species are reported to parasitize *D. saccharalis* eggs at low levels in rice grown in southeast Texas (Way and Espino 2010), and may help reduce *D. saccharalis*

populations. The study of tri-trophic interactions between rice, *D. saccharalis*, and *C. flavipes* suggest that augmentative parasitoid releases would not be profitable (Lv et al. 2011).

Extensive research has been conducted on the use of parasitoids to manage *E. loftini* populations since this insect became established in Texas sugarcane. Seventeen exotic species of hymenopteran and dipteran parasitoids were released from 1982 to 1997 in the LRGV and few have become established (Legaspi et al. 1997a, Meagher et al. 1998). The most prevalent parasitoids of *E. loftini* in the LRGV are two parasitic wasps, *Chelonus sonorensis* Cameron and *Digonogastra solitaria* Wharton & Quicke (Hymenoptera: Braconidae). The former occurs in Mexico and likely followed the expansion of its host, the latter endemically occurs both in Mexico and in the LRGV. These wasps represented together 75% of the parasitoids recovered from *E. loftini* in the LRGV in 1995-96 (Legaspi et al. 1997a). The exotic braconids *A. stigma* and *Allorhogas pyralophagus* Marsh represented together 17% of the parasitized recoveries. This *E. loftini* parasitoid complex, enhanced by yearly augmentative releases in LRGV sugarcane since the early 1980s, has achieved an increasing larval parasitism rate that has peaked in 2003/2004 when more than 25% of the larvae collected were parasitized (Meagher et al. 1998, TAES Weslaco 2005). However, stem borer injury to sugarcane has remained stable, with \approx 20% of bored internodes, since the introduction of *E. loftini* in the LRGV (Meagher et al. 1998, TAES Weslaco 2005). The parasitoids cited above are therefore unable to effectively suppress *E. loftini* infestations; nevertheless, they contribute to the overall reduction of *E. loftini* populations in Texas sugarcane. In addition, several *Trichogramma* species parasitizing *E. loftini* eggs showed encouraging results (Browning and Melton 1987, Greenberg et al. 1998). However, *Trichogramma* success under natural conditions in sugarcane fields is difficult to assess due to the concealed nature of *E. loftini* egg clusters.

Breene et al. (1993) conducted an inventory of arthropod predators in Texas sugarcane, and reported that *Solenopsis germinata* (F.) was the most abundant ant species. *Solenopsis invincta* has recently colonized the southern tip of Texas, where it is less abundant than in Louisiana fields (TAES Weslaco 2005). *Solenopsis invincta* is anticipated to provide significant control when *E. loftini* becomes established in Louisiana sugarcane (Reay-Jones et al. 2005c).

The eventuality of an *E. loftini* biological control program in rice is challenged by the same obstacles as for *D. saccharalis*. Pfannenstiel and Browning (1995) compared in a field-cage study the parasitism rate from five parasitoid species. The braconid *A. pyralophagus* and *A. stigma* parasitized 45.0 and 11.5% of the available *E. loftini* larvae, respectively, while the bethylid *Gonozius natalensis* Gordh parasitized 8.5%.

2.11. Stem Borer Management with Insecticides

2.11.1. Insecticides for *D. saccharalis* Management in Sugarcane

Insecticides remain the key means to keep *D. saccharalis* populations under economic levels in the Louisiana sugarcane industry. Bessin et al. (1990a) showed in a 3-yr field study that the pyrethroid fenvalerate achieved more than 60% of the overall control of *D. saccharalis* injury. Long and Concienne (1964) showed that the critical period for controlling *D. saccharalis* in Louisiana sugarcane was in July and August, when larvae of the second and third generations injure millable internodes. These *D. saccharalis* generations are controlled with insecticides before the larvae bore into the stalk and become protected from insecticides. Depending on cultivar and agricultural consultant recommendations, growers apply insecticides when the level of stalks infested with at least one live larva feeding in the leaf sheaths exceeds a 5 to 10% threshold (Schexnayder et al. 2001, Posey et al. 2006).

Timing and chemistry have tremendously evolved during the last decades (Hensley 1971, Reagan 2001). Insecticides in four classes are currently labeled for control of *D. saccharalis* on sugarcane in Louisiana: pyrethroids, diamides, the diacylhydrazine tebufenozide, and the benzoylphenyl urea novaluron. The pyrethroids cyfluthrin and esfenvalerate increase populations of secondary insect pests (Showler and Reagan 1991). The pyrethroids lambda-cyhalothrin and zeta-cypermethrin have been granted permanent federal labels, and following several temporary labels in sugarcane, a permanent federal label for tebufenozide was issued in 1998 (Reagan and Posey 2001).

Tebufenozide, which represented 90% of the foliar applications in 2007, is currently the most widely used insecticide on sugarcane in Louisiana (Pollet 2008). This biorational insecticide is an ecdysone agonist that causes larvae to produce a malformed cuticle (Wing et al. 1988, Dhadialla et al. 1998). Advantages of this compound include a strong specificity to certain lepidopteran pests and little to no toxicity to parasitoids and predators in sugarcane fields (Woolwine et al. 1995, Reagan et al. 1997). Despite several unsuccessful attempts to select laboratory colonies of *D. saccharalis* for resistance (Rodriguez et al. 2001), Reay-Jones et al. (2005a) determined a reduction in susceptibility among *D. saccharalis* populations in Louisiana. Subsequently, Akbar et al. (2008) obtained a 27.1-fold increase in LC_{50} after 12 generations of selection with tebufenozide in the laboratory. The development of resistance to different classes of insecticides in *D. saccharalis* populations has been a recurring problem in Louisiana sugarcane (Yadav et al. 1965, Vines et al. 1984). Thus, to mitigate the development of insecticide resistance, novaluron was granted a permanent federal label in 2009 for use on sugarcane in the United States (Beuzelin et al. 2010a). In addition, chlorantraniliprole and flubendiamide, two recently developed insecticides in the diamide class, obtained permanent

federal labels in 2010 and 2011, respectively (The Greenbook Group 2010, T. E. Reagan pers. com.).

2.11.2. Insecticides for *E. loftini* Management in Sugarcane

Legaspi et al. (1997a) recommended a threshold of 7 to 10% of leaf sheaths and blade infested with young larvae. However, *E. loftini* is active throughout the year in the LRGV and adequate control requires repeated applications due to the temporary suppression of populations provided by insecticides. Meagher et al. (1994) observed that weekly applications of monocrotophos from late May to mid-September decreased the number of bored internodes, increased yields and juice quality, and offered a net return of approximately \$900 per hectare. Weekly scheduled applications of insecticides are, however, not conceivable from an insecticide resistance perspective. Two to three applications of cyfluthrin, lambda-cyhalothrin, or tebufenozide, during the sugarcane growing season decreased the number of *E. loftini* bored internodes but did not increase yields (Legaspi et al. 1997b). In a high infestation area, even biweekly applications of tebufenozide significantly reduced *E. loftini* injury but not yield losses (Reay-Jones et al. 2005d). This lack of success using insecticides has led a majority of the LRGV sugarcane growers to abandon this control tactic. For instance, less than 0.5% of the LRGV sugarcane acreage was sprayed with insecticides in 1996-97 (Legaspi et al. 1999a).

Insecticide efficacy for *E. loftini* control in sugarcane is reduced due to the oviposition behavior of this insect (van Leerdam et al. 1986) in comparison to *D. saccharalis*. Insecticidal control of stem borers targets eggs and young larvae before they enter the sugarcane stems. In *D. saccharalis*, eggs laid on green leaves are exposed to insecticides as well as young larvae migrating from these green leaves to the space between sheaths and stems. On the other hand, in *E. loftini*, eggs laid on dry leaves in concealed sites are protected from chemicals, as well as are

young larvae located in the lower part of the plant and migrating to green parts. Insecticides alone are therefore expected not to be effective in managing *E. loftini* when it becomes established in Louisiana sugarcane (Reay-Jones et al. 2005d).

2.11.3. Insecticides for Stem Borers Infesting Rice

Insecticide applications for *D. saccharalis* control in Louisiana and Texas rice were no longer required in the 1980s, due to a decrease in infestations caused by the extensive use of insecticides for stink bug control, the use of more resistant cultivars, and the destruction of post-harvest residues (Way 1990). However, with both the establishment of *E. loftini* and the increase in *D. saccharalis* damage, farmers of the Texas rice belt have resumed insecticide sprays to avoid possible economic losses. Insecticides are typically more efficient in rice than in sugarcane because the smaller rice plants increase larval exposure to chemicals (Reay-Jones et al. 2005c). The pyrethroids lambda-cyhalothrin and zeta-cypermethrin are currently labeled in the United States for stem borer control (Reay-Jones et al. 2007a). Although the insect growth regulators tebufenozide and novaluron reduce *D. saccharalis* and *E. loftini* injury in sugarcane (Reay-Jones et al. 2005b, Beuzelin et al. 2010a), diflubenzuron, novaluron, tebufenozide, and methoxyfenozide are less efficient when compared to pyrethroids (Castro et al. 2005, Reay-Jones et al. 2007a). Reay-Jones et al. (2007a) concluded that pyrethroids applied twice during the rice reproductive phase caused the greatest decrease in whiteheads and yield losses, and would increase farmer benefits. However, the effects of insecticide applications on yield losses were highly variable. Although studies have helped to better time insecticide applications, economic thresholds have not been established (Reay-Jones et al. 2007a).

CHAPTER 3: IMPACT OF HURRICANE RITA STORM SURGE ON SUGARCANE BORER (LEPIDOPTERA: CRAMBIDAE) MANAGEMENT IN LOUISIANA¹

3.1. Introduction

The sugarcane borer, *Diatraea saccharalis* (F.), has historically been responsible for more than 90% of the arthropod-caused damage to sugarcane (interspecific hybrids of *Saccharum* spp.) in Louisiana (Reagan et al. 1972, Reagan 2001). Without a widespread use of resistant cultivars, current management is achieved by properly timed chemical control of economically damaging infestations, cultural practices, and conservation of natural enemies (Reagan and Posey 2001, Schexnayder et al. 2001, Posey et al. 2006). As shown in studies with insecticidal suppression, the arthropod predaceous complex of *D. saccharalis* can have a major impact on reducing pest infestations (Hensley et al. 1961, Reagan et al. 1972). A 16% reduction in *D. saccharalis* injury from arthropod predation was shown in a replicated field study comparing the effects of predation, sugarcane cultivar resistance, and insecticide applications (Bessin et al. 1990a). Observing arthropod predators in situ, and using correlations between predator abundance and *D. saccharalis* injury to sugarcane, Negm and Hensley (1967, 1969) found that ants (Hymenoptera: Formicidae) and spiders (Araneae) were the most important natural enemies feeding on *D. saccharalis* eggs and larvae. Numerous subsequent studies showed that the red imported fire ant, *Solenopsis invicta* Buren, was consistently the dominant natural enemy of *D. saccharalis* in Louisiana sugarcane (Reagan 1986). *Solenopsis invicta* predation contributes an estimated savings of as much as two insecticide applications a year for *D. saccharalis* control (Sauer et al. 1982). Spiders, as a group, are the primary egg predators and are second in importance in the overall *D. saccharalis* arthropod predator complex (Negm and Hensley 1969, Ali and Reagan 1986). Ground beetles (Coleoptera: Carabidae), click beetles (Coleoptera:

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Elateridae), and earwigs (Dermaptera) have also been cited as important *D. saccharalis* predators in Louisiana (Negm and Hensley 1967, 1969). Although their role has not been quantified, species of tiger beetles (Coleoptera: Carabidae: Cicindelinae) and rove beetles (Coleoptera: Staphylinidae) are also considered important components of the *D. saccharalis* predaceous complex (Negm and Hensley 1967, 1969).

On 24 September 2005, Hurricane Rita made landfall on the extreme southwestern coast of Louisiana near the border with Texas as a Category 3 hurricane (Knabb et al. 2006). Hurricanes generate strong winds, heavy rains, and tornadoes, but also cause storm surges on coasts where they make landfall. Primarily caused by hurricane high winds, storm surges are “large domes of water that sweep across the coastline” and are considered the most deadly and damaging phenomena related to hurricanes in coastal areas near sea level (NOAA 1999). Twelve thousand to 16,000 hectares of sugarcane produced in south Louisiana were flooded by salt water from Hurricane Rita storm surge (Viator et al. 2006). In addition to direct losses to the Louisiana sugarcane industry (Guidry 2005), longer-term adverse effects on soil fertility were expected due to salt deposition (Das 2005, Viator et al. 2006). However, the impacts on *D. saccharalis* and arthropod predator populations, and on insect pest management practices in the sugarcane agroecosystem, were unpredicted. During the spring of 2006, sugarcane growers and contracted agricultural consultants began observing that flooded areas seemingly had more severe *D. saccharalis* infestations, which might require earlier and more frequent insecticide applications for *D. saccharalis* control. Since *D. saccharalis* tends to infest non-stressed and actively growing plants (Hensley 1971, Botelho et al. 1977), increased oviposition was not anticipated in the salt-stressed sugarcane. However, a decrease in arthropod predation might have caused this increase in *D. saccharalis* infestations.

The objectives of this study conducted in south Louisiana sugarcane were to quantify the effects of the Hurricane Rita storm surge on 1) the abundance of soil-associated *D. saccharalis* arthropod predators and other non-predaceous soil-associated arthropods, 2) the severity of *D. saccharalis* infestations, and 3) the frequency of insecticide applications. In addition, economic losses for the crop of 2006 were determined. A follow-up survey was conducted during the spring of 2007 to determine longer-term effects of the storm surge on *D. saccharalis* infestations.

3.2. Materials and Methods

3.2.1. Field Selection

A total of 48 commercial sugarcane fields (\approx 2 to 10 ha each) were selected as a part of a stratified random survey in Vermilion, Iberia, and St Mary Parishes, Louisiana, during the summer of 2006. In zones flooded by Hurricane Rita storm surge and in non-flooded zones (1 to 15 km inland from flooded zones), 12 areas were randomly chosen and two sugarcane fields were selected in each. Sugarcane is grown in a 4 to 6-yr rotation cycle, i.e. three to five crops are harvested from a single planting, and then followed by a fallow year. Since the relative abundance of predaceous arthropods may vary with crop year (White 1980), both a plant and a ratoon sugarcane field was selected in each area. A global positioning system (GPS) unit was used to determine field location, and distances among fields were estimated in GoogleTM Earth. Among the 24 plant/ratoon field pairs, the distance was less than 1 km except for four pairs that were 3 km (2 pairs), 6 km, and 10 km apart.

3.2.2. Soil-Associated Arthropod Monitoring

Consistent with sugarcane habitat comparison studies since the 1960s (Hensley et al. 1961, Reagan et al. 1972), two pitfall traps were used in each field to determine relative soil-associated arthropod abundance. Traps consisted of 0.473-L wide mouth glass jars (Ball Corp., Broomfield,

CO) located on the top of the 10th row (19 m from margin), 15 m and 22.5 m from the headland. Traps were imbedded to soil surface and filled with 150 mL of ethylene glycol and 2 mL of liquid soap to reduce surface tension. A 15 × 15 cm metal plate, supported by a tripod elevated 3 cm above the jar, covered these traps to exclude rain, debris, and larger animals. Pitfall traps were placed in the fields on 22-23 July, and were collected and replaced 8-9 August (17-d sampling period). Traps were collected at the end of a second sampling period on 9 September (31 or 32-d sampling). For each sampling period, the arthropods collected were counted after being sorted to the following 15 groups: *S. invicta*, ants other than *S. invicta*, spiders, earwigs, ground beetles, click beetles, tiger beetles, rove beetles, scarab beetles (Coleoptera: Scarabaeidae), non-identified Coleoptera, field crickets (Orthoptera: Gryllidae), leafhoppers (Hemiptera: Cicadellidae), non-identified Hemiptera, centipedes (class Chilopoda), and non-identified other ground-dwelling arthropods.

3.2.3. Diversity and Abundance

Overall soil-associated arthropod diversity was determined with Shannon's diversity index (Southwood and Henderson 2000) calculated from the 15 arthropod groups collected (

$$H' = - \sum_{i=1}^{15} \left(\frac{n_i}{N} \right) \ln \left(\frac{n_i}{N} \right) \text{ with } n_i \text{ the number of specimens collected from arthropod group } i, \text{ and } N \text{ the}$$

total number of specimens). Predator abundance was determined considering four groups of predators: *S. invicta*, spiders, pooled predaceous beetles (ground, click, tiger, and rove beetles), and earwigs. Non-predator abundance was also determined considering three groups: field crickets, pooled non-predaceous beetles (scarab and other beetles), and pooled miscellaneous arthropods (ants other than *S. invicta*, leafhoppers, non-identified Hemiptera, centipedes, and other non-identified arthropods).

3.2.4. *Diatraea saccharalis* Injury and Insecticide Applications

At the beginning of the 2006 harvest season, *D. saccharalis* injury to sugarcane stalks was recorded as the proportion of bored internodes (12 to 24 October). Cultivars LCP 85-384, HoCP 96-540, L 97-128, and Ho 95-988 were respectively grown in 31, 13, three, and one of the fields surveyed in this study. All cultivars have shown comparable levels of susceptibility based on statistical rankings in cultivar screening experiments (Reay-Jones et al. 2003). Thus, sugarcane cultivar was assumed not to be a factor influencing differential *D. saccharalis* injury.

A total of 25 sugarcane stalks were collected from each field. Five locations were randomly chosen within a 15-m radius from the pitfall traps, and five sugarcane stalks were randomly selected at each location within a 3-m radius. The proportion of *D. saccharalis*-bored internodes was recorded for each stalk. However, due to premature harvest for seed cane production, nine fields could not be sampled for *D. saccharalis* injury (1 plant and 3 ratoon cane fields in the flooded zone, and 2 plant and 3 ratoon cane fields in the non-flooded zone). The frequency of insecticide applications made for *D. saccharalis* management was also obtained for each field.

During the spring of 2007, deadheart surveys were conducted as a follow-up to the data collected in 2006. Deadhearts are dead whorl leaves caused by *D. saccharalis* injury to sugarcane before internodes are formed, and their incidence estimates *D. saccharalis* infestations that occur during the spring (Bessin and Reagan 1993). On 15 May and 1 June 2007, a sampling area was selected in each non-fallowed sugarcane field that was previously sampled during the summer and fall of 2006. A total of 12 plant and six ratoon cane fields in the storm surge zone, and 11 plant and four ratoon fields in the non-storm surge zone were sampled. The sampling area consisted of two staggered 11-m sections of row, one row apart, starting on the 10th row and

20 m from the headland. The number of deadhearts and sugarcane stand density were recorded. Deadhearts with *D. saccharalis* injury were dissected to verify the presence of larvae.

3.2.5. Soil Analyses

For each field, a composite soil sample, made of five 30-cm-deep probes randomly located on top of rows in the vicinity of the pitfall traps (≈ 15 -m radius), was analyzed for salinity (measure of soil electrical conductivity, Soil Testing and Plant Analysis Lab, Louisiana State University, Baton Rouge, LA). Soil salinity measures were used to confirm and quantify salt water flooding from the storm surge.

3.2.6. Data Analyses

The data were analyzed as a split plot experimental design with storm surge as the main plot treatment and crop year as the subplot treatment. Generalized linear mixed models (Proc GLIMMIX, SAS Institute 2008) with a Poisson distribution were used for analysis of arthropod counts, frequency of insecticide applications, and deadheart counts. Arthropod counts were pooled over the two pitfall trap sampling dates since preliminary analyses did not indicate major differences among dates. *Diatraea saccharalis* injury estimates (proportions of bored internodes and deadhearts) were analyzed with generalized linear mixed models with binomial distributions. Generalized linear mixed models with Gaussian distributions were used for the Shannon diversity index and soil salinity analyses. The Kenward-Roger adjustment for denominator degrees of freedom (Proc GLIMMIX, SAS Institute 2008) was used in all the models to correct for inexact *F* distributions. Least square means are reported for all treatment effects to account for unbalanced data. In addition, a simple linear regression between the Shannon diversity index and *S. invicta* abundance was performed (Proc GLIMMIX, SAS Institute 2008).

3.2.7. Economic Analysis

Diatraea saccharalis-related losses in revenue were first estimated for a given zone (storm surge vs. non-storm surge), cultivar, and crop year on a per hectare basis as the sum of the cost of insecticide management and of borer-related sugar yield losses with Eq. (3.1) and (3.2).

$$LR_{ijk} = IM_i + L_{ijk} \quad (3.1)$$

$$\text{with } L_{ijk} = I_{ik} \times \frac{a_j}{100} \times Y_{ijk} \times S \quad (3.2)$$

where:

LR_{ijk} = *D. saccharalis*-related losses in revenue in \$ per hectare for zone i , with $i = 1$ and $i = 2$ for zones not affected and affected by the storm surge, respectively, for cultivar j and crop year k

IM_i = Cost of insecticide management per hectare estimated as the mean number of insecticide applications recorded for zone i , multiplied by the cost of the aerial application, \$40.76/ha [\$11.12/ha for the application and \$29.64/ha for the chemical (Salassi and Breaux 2006)]

L_{ijk} = Loss in \$ per hectare for zone i , cultivar j , and crop year k

I_{ik} = Percent bored internodes recorded for zone i and crop year k

a_j = Percent sugar yield loss per percent bored internodes for cultivar j obtained from studies conducted at the USDA-ARS-SRRC Sugarcane Research Laboratory [0.61 for LCP 85-384 and HoCP 91-555, 0.5 for Ho 95-988 and L 97-128, and 0.75 for HoCP 96-540 (White et al. 2008)]

Y_{jk} = Sugar yield in kg per hectare for cultivar j and crop year k obtained from outfield cultivar trials (Robert et al. 2007)

S = Price of sugar in \$ per kg (\$0.437/kg, Economic Research Service 2006)

The economic impact of the change in *D.saccharalis* infestations related to the Hurricane Rita storm surge was calculated as the difference in the estimated losses in revenue associated with *D.saccharalis* infestations between non-flooded and flooded zones. The projected impact on a per hectare basis was integrated over the flooded 12,000-16,000 ha of sugarcane to estimate economic consequences on the south Louisiana sugar industry. The relative production areas of sugarcane cultivars were assumed to follow the Louisiana statistics, with LCP 85-384, HoCP 96-540, HoCP 91-555, L 97-128, Ho 95-988, and other cultivars representing 73, 14, 5, 4, 2 and 2%, respectively (Legendre and Gravois 2007). By cultivar, the plant cane and ratoon cane relative production areas were also assumed to follow Louisiana statistics (Legendre and Gravois 2007).

3.3. Results

3.3.1. Soil Salinity

One year after Hurricane Rita, sugarcane fields in the zones flooded by the storm surge had significantly five-fold higher soil salt concentrations ($F = 17.94$; $df = 1, 22$; $P < 0.001$), which attained on average 806 ± 107 (SE) ppm (vs. 162 ± 107 [SE] ppm). Effects of crop year on soil salt concentrations were not detected ($F = 0.53$; $df = 1, 22$; $P = 0.473$).

3.3.2. Impact on Predaceous Arthropod Abundance

Sugarcane fields affected by the Hurricane Rita storm surge underwent a 3.4-fold decrease in *S. invicta* abundance (Table 3.1). However, as shown by the two-way storm surge by crop year interaction, the decrease in *S. invicta* abundance occurred to a greater extent in plant cane fields (5.8-fold) than in ratoon cane fields (2.0-fold). A 1.2-fold increase in *S. invicta* abundance from plant to ratoon cane fields was recorded. A total of 193 ants other than *S. invicta* ($\approx 90\%$ belonging to the genus *Hypoponera*) were collected during this study. These ants were pooled to the miscellaneous arthropod group since they were not abundant relative to *S. invicta*, which

Table 3.1. Effects of Hurricane Rita storm surge habitat disruption on the abundance (LS means \pm SE) of soil-associated arthropods collected in pitfall traps in sugarcane fields, Vermilion, Iberia, and St Mary parishes, Louisiana, 22 July-9 September 2006

	Soil-associated predators				Soil-associated non-predators			
Habitat	<i>Solenopsis invicta</i>	Spiders ^a	Predaceous beetles ^b	Earwigs ^c	Non-predaceous beetles ^d	Field crickets ^e	Misc. arthropods ^f	Total
Storm surge								
Non-flooded	143.2 ± 32.5	43.8 ± 3.1	7.8 ± 2.9	9.6 ± 2.3	4.4 ± 0.7	8.6 ± 1.4	13.4 ± 2.1	261.1 ± 36.1
Flooded	41.7 ± 9.6	36.3 ± 2.6	11.3 ± 4.2	15.7 ± 3.7	5.5 ± 0.8	10.7 ± 1.6	17.8 ± 2.8	160.5 ± 22.2
<i>F</i> ^g	14.62	3.50	0.51	2.13	1.18	0.96	1.75	6.20
<i>P</i> > <i>F</i>	0.001	0.075	0.482	0.161	0.288	0.337	0.199	0.021
Crop year								
Plant	70.0 ± 11.4	37.6 ± 2.1	18.7 ± 4.9	9.4 ± 1.6	4.5 ± 0.6	12.9 ± 1.5	17.4 ± 1.9	210.7 ± 20.7
Ratoon	85.4 ± 13.8	42.3 ± 2.3	4.7 ± 1.3	16.1 ± 2.7	5.4 ± 0.6	7.2 ± 0.9	13.6 ± 1.6	198.9 ± 19.5
<i>F</i> ^h	39.91	6.49	332.04	49.40	1.79	40.71	11.99	8.68
<i>P</i> > <i>F</i>	<0.001	0.014	<0.001	<0.001	0.188	<0.001	0.001	0.005
Storm surge × Crop year								
Non-flooded								
Plant	168.5 ± 38.3	41.5 ± 3.2	22.9 ± 8.4	8.7 ± 2.2	4.0 ± 0.7	14.2 ± 2.3	16.4 ± 2.6	320.2 ± 44.3
Ratoon	121.7 ± 27.7	46.7 ± 3.5	2.6 ± 1.0	10.6 ± 2.6	4.9 ± 0.8	5.2 ± 1.0	10.9 ± 1.8	213.0 ± 29.6
Flooded								
Plant	29.1 ± 6.7	34.2 ± 2.7	15.3 ± 5.7	10.2 ± 2.5	5.1 ± 0.9	11.6 ± 1.9	18.4 ± 2.9	138.6 ± 19.4
Ratoon	59.9 ± 13.7	38.5 ± 3.0	8.3 ± 3.1	24.3 ± 5.7	6.0 ± 1.0	9.8 ± 1.6	17.1 ± 2.7	185.7 ± 25.8
<i>F</i> ^h	279.13	0.01	104.26	19.13	0.04	20.80	5.80	320.85
<i>P</i> > <i>F</i>	<0.001	0.915	<0.001	<0.001	0.845	<0.001	0.020	<0.001

^a Araneae: \approx 50% Lycosidae, \approx 20% Linyphiidae; ^b Coleoptera: 64% Carabidae, 3% Cicindelinae, 28% Staphylinidae, 5% Elateridae;

^c Dermaptera: \approx 80% Labiduridae; ^d Coleoptera: 34% Scarabaeidae, and 66% non-identified beetles;

^e Orthoptera: 100% Gryllidae; ^f 23% non-*S. invicta* ants, 21% Cicadellidae, 10% non-identified Hemiptera, 9% Chilopoda, 37% non-identified other ground-dwelling arthropods;

^g df = 1, 21.46; 1, 21.96; 1, 22.59; 1, 17.91; 1, 24.63; 1, 23.11; 1, 23.22; and 1, 22.5, respectively; ^h df = 1, 44

represented 96.6% of the ants collected. Although proportions were not quantified, collected spiders belonged mostly to the families Lycosidae ($\approx 50\%$) and Linyphiidae ($\approx 20\%$). Flooded sugarcane showed a trend ($P \leq 0.1$) for decreased (1.2-fold) spider abundance (Table 3.1).

Unlike for *S. invicta*, differences were not detected among flooded and non-flooded fields for either predaceous beetles and earwigs (Table 3.1). For predaceous beetles, abundance decreased from plant to ratoon fields. However, the storm surge by crop year interaction showed that the decrease in abundance from plant to ratoon cane in non-flooded fields (8.6-fold) was greater than in flooded fields (1.8-fold) (Table 3.1). For earwigs, abundance increased from plant to ratoon fields. However, the storm surge by crop year interaction showed a 1.2-fold increase in abundance from plant to ratoon cane in non-flooded fields and a 2.9-fold increase in flooded fields (Table 3.1).

3.3.3. Impact on Non-Predaceous Arthropod Abundance

Differences were not detected among fields affected by the storm surge and non-flooded fields for non-predaceous beetles, field crickets, and miscellaneous arthropods. Differences were not detected between crop years for non-predaceous beetles, but field crickets and miscellaneous arthropods were 1.8-fold and 1.3-fold less abundant in ratoon fields, respectively (Table 3.1). However, the storm surge by crop year interactions for field crickets indicated a greater decrease in abundance (2.7-fold) from plant to ratoon cane in non-flooded fields than in flooded fields (1.2-fold) (Table 3.1). The same pattern was observed for miscellaneous arthropods, with a 1.5-fold decrease from plant to ratoon cane in non-flooded fields, and a 1.1-fold decrease in flooded fields.

3.3.4. Impact on Total Soil-Associated Arthropod Abundance and Diversity

The total arthropod abundance followed the same pattern as for *S. invicta*, the most abundant arthropod, which accounted for 27% (storm surge plant cane) to 62% (non-storm surge ratoon

cane) of the specimens collected. A significant 1.6-fold decrease in soil-associated arthropod abundance was associated with the storm surge (Table 3.1), and the two-way storm surge by crop year interaction showed that the decrease in abundance occurred to a significantly greater extent in plant cane fields. However, storm surge effects were not detected ($F = 0.08$; $df = 1, 22.19$; $P = 0.779$) on the total arthropod abundance when excluding *S. invicta* from the analysis. The pattern was similar to other arthropod groups such as predaceous beetles, field crickets, or miscellaneous arthropods, with a storm surge by crop year interaction ($F = 122.81$; $df = 1, 44$; $P < 0.001$) suggesting an enhanced abundance in non-*S. invicta* arthropods in ratoon fields affected by the storm surge. Differences between flooded and non-flooded sugarcane were detected for soil-associated arthropod diversity ($F = 15.51$; $df = 1, 22$; $P = 0.001$), the Shannon diversity index being 1.3-fold greater in sugarcane fields flooded by the storm surge [$H' = 1.77 \pm 0.07$ (SE) vs. $H' = 1.36 \pm 0.07$ (SE)]. Differences between crop years were not detected ($F = 0.99$; $df = 1, 22$; $P = 0.332$), and the two-way storm surge by crop year interaction was not significant ($F = 0.32$; $df = 1, 22$; $P = 0.580$). A linear negative relationship between *S. invicta* abundance and the Shannon diversity index was detected ($F = 39.77$; $df = 1, 46$; $P < 0.001$).

3.3.5. Insecticidal Management of *D. saccharalis*

A 2.4-fold greater frequency of insecticide applications for *D. saccharalis* management was recorded in fields flooded by the storm surge (Table 3.2). Sugarcane fields that had been flooded received as many as five insecticide applications (1.9 on average), whereas the maximum number of insecticide applications was three in non-flooded fields (0.8 on average).

Tebufozide [140 g (AI)/ha], an ecdysone agonist, was used in 63 of the 67 applications recorded. Lambda-cyhalothrin [37 g (AI)/ha], a pyrethroid, was used once in four fields (2 plant and 1 ratoon cane fields in flooded zones, and 1 non-flooded ratoon cane field).

Table 3.2. Insecticide application frequency for *D. saccharalis* control and end of season *D. saccharalis* injury to sugarcane (LS means \pm SE) as affected by the Hurricane Rita storm surge and crop year, Vermilion, Iberia, and St Mary parishes, Louisiana, 2006

Habitat	Insecticide applications per field	<i>D. saccharalis</i> injury ^a
Storm surge		
Non-flooded	0.8 \pm 0.2	3.0 \pm 1.0
Flooded	1.9 \pm 0.3	8.1 \pm 2.3
<i>F</i> ^b	8.04	5.25
<i>P</i> > <i>F</i>	0.010	0.032
Crop year		
Plant	1.3 \pm 0.3	8.0 \pm 1.7
Ratoon	1.2 \pm 0.2	3.1 \pm 0.7
<i>F</i> ^c	0.01	158.21
<i>P</i> > <i>F</i>	0.981	<0.001
Storm surge \times Crop year		
Non-flooded		
Plant	0.7 \pm 0.3	6.0 \pm 1.8
Ratoon	0.9 \pm 0.3	1.5 \pm 0.5
Flooded		
Plant	2.1 \pm 0.5	10.6 \pm 3.0
Ratoon	1.7 \pm 0.4	6.1 \pm 1.8
<i>F</i> ^c	0.60	27.36
<i>P</i> > <i>F</i>	0.444	<0.001

^a Percent bored internodes recorded in mid-October 2006

^b df = 1, 21.44 for insecticide applications; 1, 20.93 for percent bored internodes

^c df = 1, 44 for insecticide applications; 1, 35 for percent bored internodes

3.3.6. *Diatraea saccharalis* Injury in the Fall 2006

Even with the increased number of insecticide applications in fields affected by the Hurricane Rita storm surge, a 2.7-fold higher level of *D. saccharalis* injury was observed near harvest time, with an average of 8.1% bored internodes (Table 3.2). Borer injury was 2.6 times greater in plant cane fields than in ratoon fields, and the storm surge by crop year interaction showed that the difference in injury among flooded and non-flooded fields was greater in ratoon cane (4.1 vs. 1.8-fold).

3.3.7. *Diatraea saccharalis* Injury in the Spring 2007

Effects of the storm surge on *D. saccharalis*-caused deadheart number ($F = 0.84$; $df = 1$, 17.69; $P = 0.373$) and proportion relative to stand density ($F = 0.40$; $df = 1$, 17.68; $P = 0.538$) were not detected during the spring of 2007. Fewer deadhearts were recorded in plant cane than in ratoon cane fields for the number ($F = 5.01$; $df = 1$, 29; $P = 0.033$) and the proportion ($F = 6.96$; $df = 1$, 29; $P = 0.014$) of deadhearts. However, the storm surge by crop year interactions for the number ($F = 15.18$; $df = 1$, 29; $P = 0.001$) and proportion ($F = 13.34$; $df = 1$, 29; $P = 0.001$) of deadhearts indicated that non-storm surge ratoon and storm surge plant cane fields had greater infestations than non-storm surge plant cane fields and storm surge ratoon cane fields, respectively. Because only a limited sample was available for ratoon fields, deadheart abundance estimates were also analyzed considering only the storm surge effect. The number of deadhearts in flooded fields averaged 986 ± 238 (SE) per hectare and 454 ± 132 (SE) per hectare in non-flooded fields ($F = 4.21$; $df = 1$, 18.11; $P = 0.055$). Deadhearts represented $0.68\% \pm 0.15$ (SE) and $0.37\% \pm 0.10$ (SE) of the sugarcane stands ($F = 2.85$; $df = 1$, 17.56; $P = 0.109$) in flooded and non-flooded fields, respectively. This analysis showed trends ($P \leq 0.1$) for approximately two-fold higher *D. saccharalis* injury in fields 20 months after the storm surge. A total of 29 *D. saccharalis* larvae were recovered from the collected deadhearts. Considering only the storm surge effect, differences were not detected ($F = 0.27$; $df = 1$, 19.24; $P = 0.607$) with on average 0.72 and 0.92 larvae collected in flooded and non-flooded fields, respectively.

3.3.8. Economic Impact

Losses in revenue associated with *D. saccharalis* pest damage in fields that had been flooded by the hurricane storm surge attained \$154 and \$148 per hectare for plant and ratoon cane fields, respectively, for the most popular cultivar LCP 85-384. For HoCP 96-540, the second most

popular cultivar, the economic impact attained \$211 and \$185 per hectare, for plant and ratoon cane fields, respectively. Estimated economic losses peaked at \$264 per hectare for cultivar Ho 95-988 plant cane fields, and averaged \$164 per hectare when weighed by the relative cultivar and crop year production areas. The *D. saccharalis* economic impact determined from losses in revenue on a per hectare basis over the 12,000 to 16,000 ha of flooded sugarcane was between \$1,964,000 and \$2,619,000 for the 2006 crop.

3.4. Discussion

3.4.1. Storm Surge Effects on *D. saccharalis* Management

Data collected in this study showed that unusually high *D. saccharalis* infestations occurred in sugarcane fields flooded by Hurricane Rita storm surge, and that decreased *S. invicta* populations were at least partially associated with these storm surge areas. The most important group suppressing *D. saccharalis* populations in sugarcane (Negm and Hensley 1967, 1969) therefore appeared affected by the storm surge, and based on numerous previous studies (Reagan 1986, Bessin et al. 1990a), this decline likely increased *D. saccharalis* infestations. Louisiana sugarcane growers treat sugarcane with insecticides when *D. saccharalis* infestations approach the action threshold of five percent of stalks with at least one live larva in the leaf sheaths (Schexnayder et al. 2001). This study showed that growers had to treat more (2.4-fold increase) in zones impacted by the hurricane storm surge, and even with an average increase in insecticide use, higher *D. saccharalis* injury levels were recorded. Tebufenozide was used in 94% of the insecticide applications recorded in this study. This ecdysone agonist is very specific to lepidopterans and does not have deleterious effects on sugarcane non-target arthropod communities (Reagan and Posey 2001). Therefore it is our contention that increased frequency of

insecticide applications in fields flooded by the storm surge did not impact soil-associated arthropods, including *S. invicta*.

3.4.2. Sugarcane Soil-Associated Arthropod Fauna Ecology

Only *S. invicta* appeared to be negatively impacted 10-12 mo after the areawide habitat disruption caused by the storm surge flooding. When plunged into freshwater, *S. invicta* individuals gather and form floating clusters that can drift for more than a week without drowning (Hölldobler and Wilson 1990). However, Wiltz and Hooper-Búi (2006) reported that under laboratory conditions *S. invicta* is susceptible to salt water, sinking within 30 min when in 3.5 percent salt water (approximately equal to seawater), and within 48 h in one percent salt water. In addition, mated *S. invicta* queens have limited dispersal abilities, moving typically less than 1.6 km during nuptial flights that occur in the spring and summer (Tschinkel 2006). Susceptibility to saltwater flood and limited dispersal abilities may explain why *S. invicta* was negatively impacted by the storm surge and slow to recover back to pre-hurricane population levels.

Spiders possess excellent dispersal abilities, becoming airborne and dispersing passively (Pearce et al. 2005). Ballooning from both adjacent and distant habitats was shown to be a key process in the rapid colonization of corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] systems for linyphiids, lycosids, oxyopids, and araneids (Bishop and Riechert 1990, Pearce et al. 2005). Despite possible negative impacts of the storm surge, spiders may have quickly re-colonized formerly flooded sugarcane fields. This may explain the absence of a storm surge effect on spider abundance. In addition, both decreased competition and predation from *S. invicta* may also have facilitated spider recovery in storm surge zones. Vinson (1991) showed that *S. invicta* negatively impacts arthropod decomposers,

preying on flies (Diptera: Tephritidae, Drosophilidae), beetles (Coleoptera: Nitidulidae, Staphylinidae), and associated hymenopterans, but also utilizing their food resource. *Solenopsis invicta* also “decimates” native ants, and has a deleterious impact on several beetle taxa in non-crop habitats (Porter and Savignano 1990). However, these authors observed no apparent effects of *S. invicta*’s invasion on spiders, and even observed positive effects on crickets (Nemobiinae) and brachypterous roaches. In cotton (*Gossypium hirsutum* L.), Eubanks et al. (2002) found that *S. invicta* reduced the survival of lady beetles (Coleoptera: Coccinellidae) and green lacewings (Neuroptera: Chrysopidae), but did not impact the survival of spiders. In Louisiana sugarcane, *S. invicta* has been observed to prey on spiders, other ants, and other arthropods (Reagan 1986). White et al. (2004) observed that among other factors, *S. invicta* contributed to preclude the establishment in Louisiana of the braconid *Cotesia flavipes* (Cameron), a parasitoid that suppresses *D. saccharalis* below economic injury levels in sugarcane of the Rio Grande Valley of Texas (Meagher et al. 1998). In light of these ecological interactions among *S. invicta* and other arthropods, it is our contention that the decreased dominance of fire ants observed in storm surge habitats may have contributed to the recovery of non-*S. invicta* arthropods. Collectively, the observed relative changes in arthropod abundance associated with the storm surge increased the soil-dwelling arthropod fauna diversity as expressed by the Shannon index.

3.4.3. Sugarcane Crop Year and Storm Surge Impact

White (1980) observed that the abundance of *S. invicta*, spiders, predaceous beetles (ground, tiger, and rove beetles), and earwigs tended to increase with the crop year. Soil-associated predators were more abundant in ratoon fields, which are typically weedier and less disturbed than plant cane fields, thus promoting arthropod prey availability and predator build-up. In our study, *S. invicta*, spiders, and earwigs were more abundant in ratoon fields, whereas predaceous

beetles, field crickets, and miscellaneous arthropods were more abundant in plant cane fields. These findings for predaceous groups are similar to those of White (1980), except for beetles.

There were differential impacts of the storm surge with the crop year. The deleterious effects of the storm surge were observed to a lesser extent in ratoon cane fields than in plant cane fields for *S. invicta*. Also, the abundance of other soil-associated arthropods was increased in flooded ratoon fields. Sugarcane ratoon fields offer more plant biomass and structural diversity because of increased weed abundance (White 1980). Also, whereas recently planted sugarcane was small in plant cane fields (< 1 m), ratoon fields were less open at the time of the storm surge because of the presence of taller sugarcane stalks (> 2 m), thus providing additional shelter to soil-associated arthropods and probably mitigating the adverse effects of the flood. The protective effect of ratoon cane biomass combined with the decreased *S. invicta* predation after the storm surge may have partially contributed to the enhanced abundance of certain arthropod groups.

3.4.4. Methodological Limitations

Not only do estimates of arthropod abundance using pitfall traps vary with arthropod absolute population size, they also vary with arthropod activity and habitat structure (Melbourne 1999, Southwood and Henderson 2000). Pitfall trap sampling alone cannot be used to provide absolute estimates of population abundances. However, this method can provide abundance estimates comparable across experimental treatments. Since ground-dwelling arthropod activity is primarily related to weather, habitat structure of the weed ground cover and other surface features, comparisons are valid under the same weather and physical environment. In this study, non-flooded areas were one to 15 km inland from storm surge flooded areas, and the distance between plant and ratoon cane fields within each area was minimized, thus reducing weather and extraneous variation across experimental treatments.

3.4.5. Concluding Remarks

Diatraea saccharalis management in Louisiana sugarcane relies on narrow-range minimum-risk insecticides and associated conservation of arthropod predators. This study suggests that Hurricane Rita disturbed the pest management stability between beneficial and pest arthropods for the subsequent production season, requiring additional insecticide applications and causing economic losses. However, *D. saccharalis*-caused deadheart data collected 20-21 months after the hurricane provided additional insights, showing only trends for differences among storm surge and non-storm surge areas, and suggesting that the *D. saccharalis* arthropod predatory complex was in the process of recovering. South Louisiana is particularly vulnerable to severe hurricanes (Stone et al. 1997), and with shrinking coasts (Georgiou et al. 2005), devastating storm surges in sugarcane growing areas may occur again. The integration of balanced pest management tactics is essential, and resistant cultivars should play a major role in combination with selective insecticides and natural enemies to help mitigate the impact of such future natural disasters (Reay-Jones et al. 2003, Posey et al. 2006).

CHAPTER 4: SUGARCANE PLANTING DATE IMPACT ON FALL AND SPRING SUGARCANE BORER (LEPIDOPTERA: CRAMBIDAE) INFESTATIONS²

4.1. Introduction

The sugarcane borer, *Diatraea saccharalis* (F.), has historically been the most damaging arthropod in Louisiana sugarcane (hybrids of *Saccharum* spp.) (Hensley 1971, Reagan 2001). With the widespread use of susceptible high-yielding sugarcane cultivars, current *D. saccharalis* management is achieved by judiciously timed chemical control of economically damaging infestations, conservation of natural enemies, and cultural practices (Posey et al. 2006, Beuzelin et al. 2009, 2010a).

In Louisiana, sugarcane is grown in a 4 to 6-yr rotation cycle, i.e. three to five crops are harvested from a single planting and are followed by a fallow period (Salassi and Breaux 2002). Sugarcane vegetative seed pieces are planted from August to October, with the traditional peak in September. However, as farms grow larger and more diversified, planting operations have become less flexible due to simultaneous harvesting and planting activities (Garrison et al. 2000). In addition, late season production of sugarcane seed pieces has become more challenging due to early lodging of recently developed cultivars. Therefore, producers currently plant both earlier and later in the growing season (Garrison et al. 2000, Viator et al. 2005b). Planting borer-free sugarcane seed pieces is a recommended *D. saccharalis* management tactic to reduce overwintering populations (LSU AgCenter 2010b). Because of the onset of low temperatures beginning about mid-November, the growing and milling seasons are approximately 9 mo and 3-4 mo, respectively. Thus, harvest in Louisiana begins in September and is completed by early January. Sugarcane stalks are harvested close to the soil surface, and growers may leave post-harvest crop residue in the field. *Diatraea saccharalis* larvae infesting crop residues at that time

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are exposed to cold temperatures and natural enemies, which increases overwintering mortality (Kirst and Hensley 1974, Bessin and Reagan 1993). Sugarcane stubble in fallow fields should be plowed out as quickly as possible to reduce the number of overwintering larvae (LSU AgCenter 2010b). For non-fallow fields, burning of crop residue occurs mostly in the early spring.

With standard sugarcane management practices, early planting typically provides a better root establishment and higher yields (Viator et al. 2005a). Viator et al. (2005b) conducted a study to determine how August, September, and October planting dates impacted the yield of five sugarcane cultivars in Louisiana. Plant cane sugar yields for cultivar LCP 85-384 did not differ with planting dates, whereas for HoCP 85-845 and CP 70-321 sugar yields were higher for the August planting date. Charpentier and Mathes (1969) reported that fields planted in August show increased *D. saccharalis* infestations because they are highly suitable for moth oviposition. Fall sugarcane shoots (plant cane crop) and fall stubble (ratoon cane crop) are not considered to be *D. saccharalis* overwintering habitats but can serve as means of entry for larvae into seed pieces and stubble portions underground where overwintering occurs (Kirst 1973). The earlier sugarcane is planted or harvested, the greater the period of time during the late summer and fall that shoots are available for *D. saccharalis* oviposition and larval establishment. Early planted and early harvested fields may therefore represent a substantial refuge for overwintering *D. saccharalis*, and serve as a source of borers in the spring. Two field experiments were conducted between 2006 and 2008 to determine the effect of sugarcane field phenology associated with planting and harvesting dates on *D. saccharalis* infestations from the fall to the spring.

4.2. Materials and Methods

4.2.1. Planting Date Experiment 2006-2007

A field experiment was conducted from 2006 to 2007 near Patoutville (N 29.872°, W 91.744°) in Iberia Parish, LA. A randomized split-plot complete block design with 10 blocks (1

replication per block) was used. Each block was 36.9 m long and 11.0 m wide (6 rows) with four main plots, each containing two subplots. The range of phenological conditions occurring throughout the Louisiana sugarcane industry was mimicked by assigning early August, early September, early October, and late November planting dates to main plots. Each main plot was 6.4 m long and 11.0 m wide (6 rows), separated by a 1.2-m gap. Subplots were planted either with cultivar L 97-128 (*D. saccharalis* susceptible, White et al. 2008) or L 99-226 (*D. saccharalis* moderately resistant, White et al. 2008). Each subplot was 6.4 m long and three rows wide. Sugarcane was planted as whole stalks on 4 August, 2 September, 5 October, and 22 November at a density of six stalks per 6.4-m row. For each subplot, sugarcane density (shoot counts) and growth (height) were recorded from the center row during subsequent planting dates. On the third planting date (October), the number of *D. saccharalis*-caused deadhearts was recorded from the center row of each subplot for the first and second planting dates. Deadhearts are shoots with dead whorl leaves caused by herbivores damaging the apical meristem before above ground internodes are formed (Bessin and Reagan 1993). Insects such as the lesser cornstalk borer [*Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae)] and wireworms (Coleoptera: Elateridae) also cause deadhearts in sugarcane. Therefore, only deadhearts exhibiting entrance holes and frass characteristic of *D. saccharalis*, but no silken tubes (characteristic of *E. lignosellus*), were recorded. Additionally, a 2.1-m long section of row was randomly selected from one outer row of each subplot, and plants from this section were destructively sampled for *D. saccharalis*. The number of injured shoots, injured shoots turned into deadhearts, as well as the abundance and size of *D. saccharalis* immatures found within the injured shoots were recorded. The size of *D. saccharalis* larvae was visually determined, with small, intermediate, and large larvae corresponding approximately to first-second, third, and

fourth-fifth instars, respectively. On the fourth planting date (November), the number of *D. saccharalis*-caused deadhearts was recorded from the center row of each subplot from the first, second, and third planting dates. The following spring (18 May and 7 June), numbers of shoots and deadhearts found in the center row were recorded. Deadhearts were collected and dissected for *D. saccharalis* immatures, whose number and size were recorded.

4.2.2. Planting Date Experiment 2007-2008

A second field experiment was conducted from 2007 to 2008 near Bunkie (N 30.950°, W 92.163°) in Avoyelles Parish, LA. A randomized split-plot complete block design with four blocks (1 replication per block) was used. Each block was 53.6 m long and 14.6 m wide (8 rows), and contained four main plots, one for each planting date. Main plots were 12.5 m long and 14.6 m wide (8 rows), separated by a 1.2-m gap. Subplots were planted with cultivar Ho 95-988 (*D. saccharalis* susceptible, White et al. 2008) or L 99-226. Each subplot was 12.5 m long and 7.3 m wide (4 rows). Sugarcane was planted as whole stalks, at a density of 14 to 20 stalks per 12.5-m row, on 6 August, 5 September, 10 October, and 21 November. Sugarcane emergence and growth data collection was conducted on the two center rows of each subplot in the same manner as that of the 2006-2007 experiment. On the third planting date, the number of *D. saccharalis*-caused deadhearts was recorded from the two center rows of each subplot from the first and the second planting dates. Additionally, sugarcane shoots for each subplot were examined from one randomly selected outer row. The number of injured shoots, injured shoots turned into deadhearts, and the abundance and size of *D. saccharalis* immatures found within the injured shoots were recorded. On the fourth planting date, the number of *D. saccharalis*-caused deadhearts was recorded from the two center rows of each subplot from the first, second, and third planting dates. The following spring (12 and 28 May), numbers of shoots and deadhearts

found in the two center rows were recorded. Deadhearts were collected and dissected for *D. saccharalis* immatures, with immature number and larval size recorded.

4.2.3. Data Analyses

Data from experiments initiated in 2006 and 2007 were analyzed separately. Analyses of variance (ANOVAs) were conducted using Proc GLIMMIX (SAS Institute 2008), and linear regressions were conducted using Proc REG (SAS Institute 2008). Data collected in early October from destructive sampling (*D. saccharalis*-caused deadheart, *D. saccharalis*-injured shoot, and *D. saccharalis* immature counts), and data collected during the spring (shoot, *D. saccharalis*-caused deadheart, and *D. saccharalis* immature counts) were compared using two-way ANOVAs with planting date and cultivar as factors. Shoot count, plant size, and deadheart count data collected from periodic sampling of subplot center rows during the fall were compared using three-way repeated measures ANOVAs with planting date, cultivar, and observation date as factors. A variance component covariance structure was used to model the effects of repeated measures. In the experiment initiated in 2007, each of the two subplot center rows was considered a sampling unit. The Kenward-Roger adjustment for denominator degrees of freedom was used in all the ANOVA models to correct for inexact F distributions (Proc GLIMMIX, SAS Institute 2008). When ANOVA effects were detected ($P < 0.05$), least square means were separated using the least significant difference (LSD, $\alpha = 0.05$). Least square means \pm standard errors on a per hectare basis are reported.

Linear regressions were conducted to determine whether a relationship between *D. saccharalis* and deadheart counts (recorded from destructive sampling in early October) was detected. In addition, linear regressions between fall (late November) and spring deadheart

counts (recorded from subplot center rows) were conducted to investigate the relationship between end and beginning of the year *D. saccharalis* infestations in newly planted sugarcane.

4.3. Results

4.3.1. Sugarcane Availability

Planting date, observation date, and planting date by observation date interaction effects were detected ($P < 0.05$) for plant availability estimates (shoot density and plant height) from periodic sampling during the fall of 2006 and 2007 (Table 4.1). In 2006, differences in shoot densities between cultivars L 99-226 and L 97-128 were not detected ($F = 0.00$; $df = 1, 54$; $P = 0.984$). August plantings had $33,178 \pm 1,764$ shoots/ha by early September. In early October, September plantings had emerged with 47% lower shoot densities (Fig. 4.1) than the August plantings. In late November, the October plantings had the lowest shoot densities, 5.1-fold and 2.9-fold less than August and September plantings, respectively. Plant height followed a pattern similar to that observed for shoot density (Fig. 4.1). In early September, August plantings measured 47.0 ± 1.3 cm. By late November, the October plantings had the smallest plants, 3.7-fold and 2.3-fold smaller than August and September plantings, respectively. In addition to a numerical trend ($F = 3.19$; $df = 1, 27$; $P = 0.085$) for L 99-226 plants being taller than L 97-128 plants, a significant cultivar by planting date two-way interaction was detected ($F = 7.87$; $df = 2, 27$; $P = 0.002$). L 99-226 plants from August plantings were 9% taller than L 97-128 plants whereas cultivar differences were not detected in other plantings. Whereas shoots growing from the first three plantings were available during the fall, shoots from the November plantings did not emerge until the following year (Fig. 4.1).

Shoot density and plant height during the fall of 2007 showed patterns comparable to those observed in 2006, with early plantings having increased availability and the last planting not

emerging until the following year (Fig. 4.1). In early September, the August plantings had $53,808 \pm 2,538$ shoots/ha that measured 50.7 ± 1.9 cm. In late November, August plantings shoot density was 1.4-fold and 10.9-fold greater than that of September and October plantings, respectively. August plantings were 1.9-fold and 5.9-fold taller than those from September and October plantings, respectively. Shoot density and plant height were also affected by cultivar ($F = 5.41$; $df = 1, 18$; $P = 0.032$ and $F = 49.99$; $df = 1, 9$; $P < 0.001$, respectively), with L 99-226 showing greater density (13%) and height (23%) than Ho 95-988. However, two-way and three-way interactions involving cultivar effects were also detected ($P < 0.05$). Although L 99-226 generally had higher shoot densities than Ho 95-988 (Fig. 4.1), the cultivar by observation date interaction ($F = 3.38$; $df = 2, 84$; $P = 0.039$) and the planting date by observation date by cultivar ($F = 12.34$; $df = 4, 84$; $P < 0.001$) interaction showed that differences in shoot density between L 99-226 and Ho 95-988 at each observation date changed to varying extents for each planting date (Fig. 4.1). For August plantings, L 99-226 had 50% higher shoot densities than Ho 95-988 in early September; however, differences were not detected (LSD $P > 0.05$) during later sampling. For September plantings, L 99-226 had 39 and 31% higher shoot densities than Ho 95-988 in early October and late November, respectively. For October plantings, differences in shoot densities between L 99-226 and Ho 95-988 in late November were not detected (LSD $P > 0.05$). The cultivar by observation date ($F = 4.66$; $df = 2, 108$; $P = 0.011$), cultivar by planting date ($F = 9.45$; $df = 2, 9$; $P = 0.006$), and the three-way ($F = 2.95$; $df = 4, 108$; $P = 0.023$) interactions showed that differences in plant height between L 99-226 and Ho 95-988 at each observation date changed to varying extents for each planting date (Fig. 4.1). For August plantings, L 99-226 was 35, 22, and 13% taller than Ho 95-988 in early September, early October, and late November, respectively. For September plantings, L 99-226 was 24 and 26% taller than Ho 95-988 in mid-

October and late November, respectively. For October plantings, L 99-226 was 51% taller than Ho 95-988 in late November.

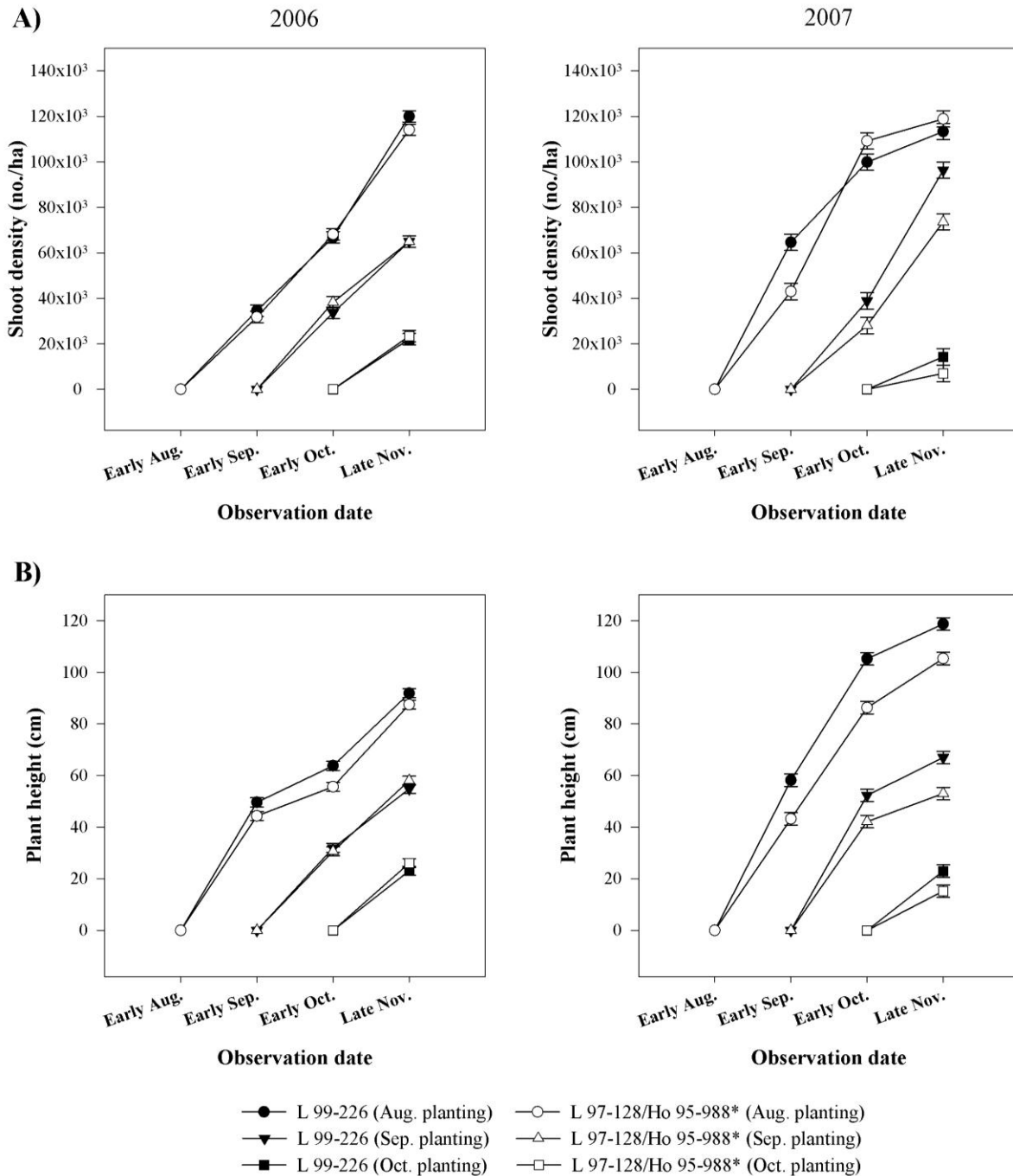


Fig. 4.1. (A) Sugarcane shoot densities and (B) plant heights (LS means \pm SE) during the fall from planting date field experiments in Patoutville (2006) and Bunkie (2007), Louisiana.

*Cultivar L 97-128 for 2006 plantings and Ho 95-988 for 2007 plantings

Table 4.1. Selected statistical comparisons for shoot densities, plant height, and deadheart densities from sugarcane planted on four dates ranging from early August to late November, 2006 and 2007

Comparison	Fall 2006			Fall 2007		
	<i>F</i>	df	<i>P</i> > <i>F</i>	<i>F</i>	df	<i>P</i> > <i>F</i>
Shoot density						
Planting date	746.46	2, 54	<0.001	504.34	2, 18	<0.001
Observation date	993.33	2, 108	<0.001	541.07	2, 84	<0.001
Planting date × Observation date	105.03	4, 108	<0.001	115.35	4, 84	<0.001
Plant height						
Planting date	1047.71	2, 18	<0.001	853.93	2, 6	<0.001
Observation date	1141.93	2, 108	<0.001	890.50	2, 108	<0.001
Planting date × Observation date	74.33	4, 108	<0.001	113.46	4, 108	<0.001
Deadheart density						
Planting date	54.23	2, 54	<0.001	11.67	2, 9	0.003
Observation date	20.81	1, 54	<0.001	13.13	1, 42	<0.001
Planting date × Observation date	4.20	2, 54	0.020	8.49	2, 42	<0.001

4.3.2. *Diatraea saccharalis* Fall Infestations

Planting date, observation date, as well as planting date by observation date two-way interaction effects were detected ($P < 0.05$) for *D. saccharalis*-caused deadheart densities from periodic sampling during the fall of 2006 and 2007 (Table 4.1). Differences in deadheart densities as affected by sugarcane cultivar were not detected ($F = 0.26$; $df = 1, 54$; $P = 0.614$ in 2006 and $F = 0.51$; $df = 1, 9$; $P = 0.492$ in 2007). In early September, deadhearts in August plantings were not observed in 2006 and 2007 (Fig. 4.2). In early October, August plantings had higher deadheart densities than September plantings (4,313 vs. 43 and 1,093 vs. 0 deadhearts/ha in 2006 and 2007, respectively). In late November 2006, October plantings had the lowest deadheart densities, 37.8-fold and 9.8-fold less than August and September plantings, respectively. September plantings had intermediate deadheart densities, 3.9-fold less than August plantings (Fig. 4.2). *Diatraea saccharalis* adult emergence holes, indicating life cycle completion, were observed in deadhearts

from sugarcane planted in August [$641 \pm 1,069$ exit holes/ha (mean \pm SD)]. In late November 2007, deadhearts were not observed in October plantings whereas early September plantings had 13.0-fold less deadhearts than August plantings (Fig. 4.2).

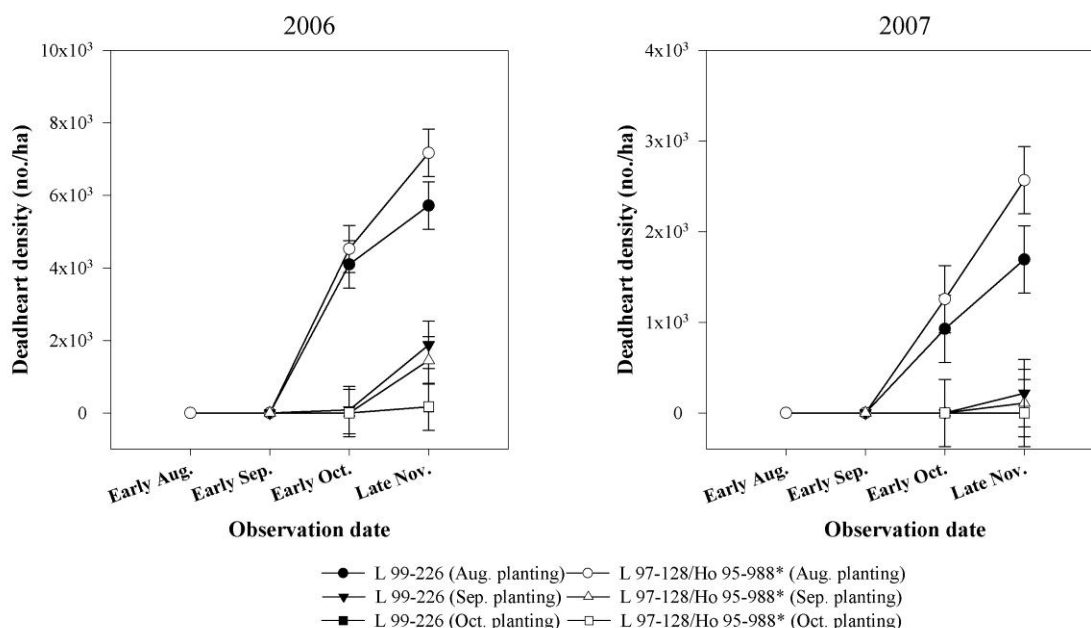


Fig. 4.2. *Diatraea saccharalis*-caused deadheart densities (LS means \pm SE) during the fall in sugarcane from planting date field experiments in Patoutville (2006) and Bunkie (2007), Louisiana. *Cultivar L 97-128 for 2006 plantings and Ho 95-988 for 2007 plantings

In early October 2006, after shoot examination and destructive sampling from border rows of August and September plantings, differences in deadheart densities were not detected (Table 4.2). Even in the absence of deadheart symptoms, some sugarcane shoots were injured with *D. saccharalis* feeding signs in leaf sheaths and boring into the stem. The density of these non-deadheart injured sugarcane shoots was greater (2.3-fold) in August vs. September plantings (Table 4.2). In addition, there were differences in *D. saccharalis* infestations (Table 4.2), with August plantings harboring 4.7-fold more borers than September plantings. Differences between cultivars L 99-226 and L 97-128 for deadheart densities, non-deadheart injured shoot densities,

Table 4.2. Deadheart densities, non-deadheart injured shoot densities, and *D. saccharalis* infestations (LS means \pm SE) observed in early October from sugarcane planted in early August and early September, 2006 and 2007

Sugarcane	Fall 2006			Fall 2007		
	Deadheart density	Non-deadheart injured shoot density	<i>D. saccharalis</i> density	Deadheart density	Non-deadheart injured shoot density	<i>D. saccharalis</i> density
Planting date						
Early Aug.	1,196 \pm 384	2,306 \pm 422 a	2,220 \pm 541 a	3,933 \pm 990 a	819 \pm 326	2,076 \pm 432 a
Early Sep.	1,068 \pm 384	982 \pm 422 b	470 \pm 541 b	164 \pm 990 b	55 \pm 326	109 \pm 432 b
F^a	0.06	4.92	5.24	7.25	3.59	12.46
$P > F$	0.817	0.033	0.034	0.036	0.155	0.039
Cultivar						
L 99-226	1,110 \pm 331	1,708 \pm 422	1,324 \pm 481	1,475 \pm 786	492 \pm 274	656 \pm 362 b
L 97-128/Ho 95-988 ^b	1,153 \pm 331	1,580 \pm 422	1,366 \pm 481	2,622 \pm 786	382 \pm 274	1,530 \pm 362 a
F^c	0.01	0.05	0.01	2.57	0.32	8.73
$P > F$	0.911	0.831	0.943	0.160	0.595	0.026
Planting date \times Cultivar						
Early Aug.						
L 99-226	1,110 \pm 468	2,477 \pm 597	2,050 \pm 680	2,622 \pm 1,112	874 \pm 354	1,093 \pm 480 b
L 97-128/Ho 95-988 ^b	1,281 \pm 468	2,135 \pm 597	2,391 \pm 680	5,244 \pm 1,112	765 \pm 354	3,059 \pm 480 a
Early Sep.						
L 99-226	1,110 \pm 468	939 \pm 597	598 \pm 680	328 \pm 1,112	109 \pm 354	219 \pm 480 b
L 97-128/Ho 95-988 ^b	1,025 \pm 468	1,025 \pm 597	342 \pm 680	0 \pm 1,112	0 \pm 354	0 \pm 480 b
F^c	0.11	0.13	0.26	4.25	0.00	13.64
$P > F$	0.739	0.723	0.615	0.085	1.000	0.0102

LS means in columns followed by the same letter are not different (LSD, $\alpha = 0.05$)

^a df= 1,18; 1,36; 1,18; 1,6; 1,3; and 1,3, respectively

^b Cultivar L 97-128 for fall 2006 and Ho 95-988 for fall 2007

^c df = 1, 18; 1, 36; 1, 18; 1, 6; 1, 6; and 1, 6, respectively

and *D. saccharalis* infestations were not detected ($P > 0.05$, Table 4.2). Among the *D. saccharalis* larvae that were collected in August and September plantings, 25 and 27% were small, 40 and 18% were intermediate, 35 and 55% were large, respectively. A linear regression ($F = 9.09$; $df = 1, 38$; $P = 0.005$; $R^2 = 0.193$) showed that *D. saccharalis* infestations in early October (dependent variable) were positively correlated with deadheart densities [*slope*: 0.694, 95% C.I. = (0.228, 1.161); *intercept*: 0.655, 95% C.I. = (-0.331, 1.642)].

In early October 2007, shoot examination and destructive sampling from border rows showed that more *D. saccharalis*-caused deadhearts (24.0-fold) occurred in August than in September plantings (Table 4.2). There was a numerical trend for greater deadheart differences between August and September plantings in cultivar Ho 95-988 ($P \leq 0.10$ for the planting date by cultivar interaction, Table 4.2) than in L 99-226. More *D. saccharalis* larvae were collected in August than in September plantings (19.0-fold), and in Ho 95-988 than in L 99-226 (2.3-fold). The significant ($P < 0.05$) planting date by cultivar interaction showed that differences in *D. saccharalis* infestations between August and September plantings occurred to a greater extent in cultivar Ho 95-988 than in L 99-226 (Table 4.2). Among the *D. saccharalis* larvae that were collected from August plantings, 3, 11, and 86% were small, intermediate, and large, respectively. All larvae recovered from September plantings were large. A linear regression ($F = 241.60$; $df = 1, 14$; $P < 0.001$; $R^2 = 0.945$) showed that *D. saccharalis* infestations in early October (dependent variable) were positively correlated with deadheart densities [*slope*: 0.500, 95% C.I. = (0.431, 0.569); *intercept*: 0.158, 95% C.I. = (-0.396, 0.712)]. Destructive sampling data collected in October 2006 did not differentiate *D. saccharalis* in deadhearts from *D. saccharalis* in non-deadheart injured shoots. However, data from 2007 showed that 68% of recovered borers were infesting deadhearts from the August planting date. Despite the presence of deadhearts, all

D. saccharalis larvae collected from the September planting date were feeding in non-deadheart injured shoots.

4.3.3. *Diatraea saccharalis* Spring Infestations

Differences in sugarcane shoot densities during the spring changed with planting dates (Table 4.3, Fig. 4.3). During the spring of 2007 and 2008, sugarcane planted in August (2006 and 2007, respectively) had higher shoot densities than that planted in September (14 and 25%, respectively), October (51 and 76%, respectively), and November (87 and 97%, respectively). Sugarcane planted in September (2006 and 2007) had higher shoot densities than that planted in October (33 and 41%, respectively) and November (65 and 58%, respectively). However, the effect of planting dates during the spring of 2007 occurred to a different extent in L 99-226 vs. L 97-128 (Fig. 4.3), as shown by the significant two-way planting date by cultivar interaction (Table 4.3). In addition, shoot densities in L 99-226 plots were 30% higher than those in Ho 95-988 plots during the spring of 2008 (Fig. 4.3).

Differences in deadheart densities and *D. saccharalis* infestations from deadhearts during the spring were not detected among planting dates (Table 4.3). Among *D. saccharalis* immatures infesting deadhearts during the spring of 2007, 25% were intermediate, 71% were large, and 4% were pupae. Pupae were recovered from deadhearts collected from September and November plantings. Among *D. saccharalis* larvae infesting deadhearts during the spring of 2008, 26% were intermediate and 74% were large. No pupae were recovered. Linear regressions conducted on data from experiments initiated in 2006 and 2007 did not detect a correlation ($F = 0.30$; $df = 1, 78$; $P = 0.583$; $R^2 = 0.004$ and $F = 3.74$; $df = 1, 62$; $P = 0.058$; $R^2 = 0.057$, respectively) between deadheart densities observed during the fall (late November) and the subsequent spring (May-June).

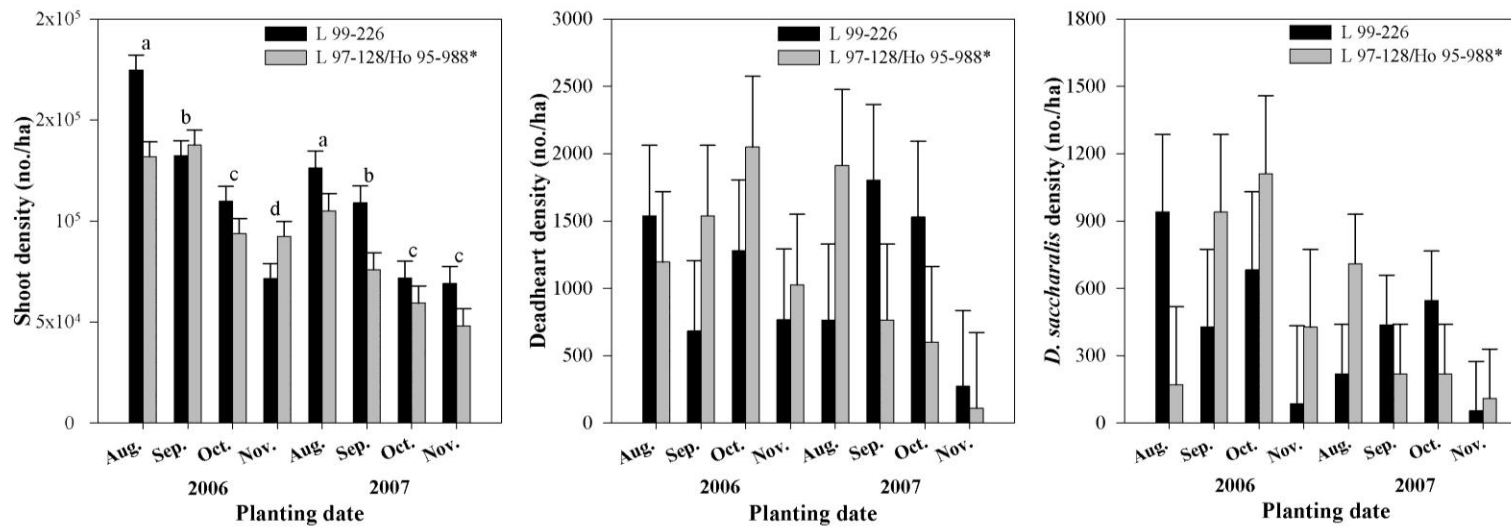


Fig. 4.3. Shoot densities, deadheart densities, and *D. saccharalis* infestations in deadhearts (LS means + SE) during the spring from sugarcane planted on four dates ranging from early August to late November, 2006 and 2007, Louisiana. Planting dates within a year followed by the same letter are not different (LSD, $\alpha = 0.05$); however, letters were not included when all bars were not different.
 *Cultivar L 97-128 for 2006 plantings and Ho 95-988 for 2007 plantings

Table 4.3. Statistical comparisons for shoot densities, deadheart densities, and *D. saccharalis* infestations in deadhearts from sugarcane planted on four dates ranging from early August to late November

Comparison	Spring 2007			Spring 2008		
	<i>F</i>	df	<i>P</i> > <i>F</i>	<i>F</i>	df	<i>P</i> > <i>F</i>
Shoot density						
Planting date	38.43	3, 27	<0.001	19.26	3, 24	<0.001
Cultivar	5.50	1, 36	0.025	13.58	1, 24	0.001
Planting date × Cultivar	15.62	3, 36	<0.001	0.52	3, 24	0.675
Deadheart density						
Planting date	0.80	3, 72	0.497	1.51	3, 9	0.277
Cultivar	1.08	1, 72	0.303	0.49	1, 44	0.486
Planting date × Cultivar	0.55	3, 72	0.647	2.07	3, 44	0.118
<i>D. saccharalis</i> density						
Planting date	1.16	3, 36	0.337	0.97	3, 9	0.448
Cultivar	0.28	1, 36	0.601	0.00	1, 44	1.000
Planting date × Cultivar	1.54	3, 36	0.221	1.75	3, 44	0.170

4.4. Discussion

In this 2-yr study, sugarcane was planted on four dates from the first week of August to the third week of November to reproduce sugarcane phenologies associated with planting and harvesting operations in Louisiana. Because several crops are harvested from a single planting, 25-30% of the Louisiana sugarcane production area is replanted each year using vegetative seed pieces produced from the harvest of 6.5% of the acreage (Legendre and Gravois 2001, 2006, 2010). This study showed that sugarcane fields planted (or harvested) in early August offer an extended period of plant availability for *D. saccharalis* infestations, with higher shoot densities and taller plants (increased biomass) than fields planted (or harvested) later in the summer or fall. Late November plantings did not produce vegetation until the following spring, suggesting that sugarcane fields planted (or harvested) after late November preclude the growth of a suitable host substrate for *D. saccharalis* oviposition.

Sampling throughout the fall showed that early August plantings had higher *D. saccharalis* deadheart densities than later planted sugarcane. This suggests that sugarcane earlier availability and greater biomass associated with early plantings increased *D. saccharalis* infestations. Destructive sampling conducted in early October confirmed that greater deadheart densities were associated with higher *D. saccharalis* infestations. Although Charpentier and Mathes (1969) commented that August planting dates were associated with increases in *D. saccharalis* infestations in Louisiana, our study is the first to quantify and compare fall infestations in newly planted sugarcane under current Louisiana production practices. Data from this study suggested a potential for increased *D. saccharalis* overwintering populations in early plantings associated with greater infestations during the fall. However, differences in deadhearts and *D. saccharalis* infestations in deadhearts were not detected during the spring. Four to five overlapping *D. saccharalis* generations occur annually in Louisiana (Hensley 1971). After being induced in the first two larval stadia (Roe et al. 1984), *D. saccharalis* enters a form of diapause as a large larva, with a peak incidence (63 to 71% of field populations) between October and December under Louisiana conditions (Katiyar and Long 1961). Although crop residues that are left in the field after harvest may initially be infested with larvae, they decay rapidly and do not serve as habitat for overwintering *D. saccharalis* populations (Kirst and Hensley 1974). The main overwintering habitats are underground portions of vegetative seed pieces and stubble. Because *D. saccharalis* larvae can use fall shoots to gain access to their underground overwintering habitat (Kirst and Hensley 1974) and greater fall infestations were found in early plantings, differences in deadhearts and *D. saccharalis* infestations were expected during the spring.

Deadheart incidence estimates the level of *D. saccharalis* infestations that occur during the spring in sugarcane (Bessin and Reagan 1993). *Diatraea saccharalis* larvae found in spring

deadhearts from our study were a combination of intermediate and large larvae, indicating that both overwintering and first generation borers were infesting the deadhearts. Although deadhearts provide appropriate estimates for *D. saccharalis* spring infestations, they were not adequate for determining infestations that had successfully overwintered in newly planted sugarcane. In addition, the small size of our experimental plots likely increased the redistribution of adults among plots in the late fall and spring, thus mitigating potential differences in overwintering larval infestations. Red imported fire ants (*Solenopsis invicta* Buren), the primary *D. saccharalis* natural enemies in Louisiana sugarcane (Bessin and Reagan 1993; Beuzelin et al. 2009), were not artificially suppressed and may also have increased variability in spring *D. saccharalis* infestations. Some overwintering mortality factors (i.e., temperature, flooding) likely impacted overwintering populations to the same extent regardless of *D. saccharalis* densities. However, density dependent mortality factors (i.e., predation, parasitism) may have decreased infestations to a greater extent in more heavily infested sugarcane. Because of methodological weaknesses and potential interactions among overwintering mortality factors, a better assessment of overwintering populations should have been conducted during the winter and spring. During the experiment initiated in 2006, destructive sampling of underground seed pieces was conducted in January from 2.1-m long sections of border row for each subplot. Only one overwintering *D. saccharalis* larva was recovered and sampling was extremely labor intensive. The use of field cages collecting moths emerging from overwintering infestations may assist in better determining the role of sugarcane phenology during the fall on *D. saccharalis* overwintering populations (e.g., Kfir et al. 1989).

Although a practice of some insect pest management programs (Pedigo 2002), the manipulation of planting dates is more often associated with the agronomic management of crops.

Because sugarcane stalks are the shortest in August, greater areas have to be harvested for seed piece production to achieve optimal planting rates. However, seed pieces are easier to harvest and plant in August before sugarcane stalks bend due to lodging (Viator et al. 2005a, 2005b). In addition, early planted sugarcane tends to produce higher yields associated with better root establishment (Viator et al. 2005a, 2005b, Hoy et al. 2006). Nevertheless, the effect of planting dates on yields is dependent on cultivar, with cultivar-specific optimal planting dates. Different cultivars may also show varying degrees of yield response to planting dates. In addition, planting date effects on yields vary with planting methods (Viator et al. 2005a, Hoy et al. 2006). In our study, sugarcane was planted as whole stalks. Louisiana growers also plant sugarcane as billets (stalk sections of 50-60 cm, Viator et al. 2005a). The yield response to planting dates of billet- vs. whole stalk-planted sugarcane seems less consistent (Viator et al. 2005a, Hoy et al. 2006). Whereas early planted sugarcane may increase regional *D. saccharalis* populations during the spring, better root establishment and greater biomass may help compensate for borer injury during the spring, which might help protect yields. Early planting dates have also been reported to reduce losses associated with root injury from wireworms (Charpentier and Mathes 1969).

L 99-226, L 97-128, and Ho 95-988 are three commercial sugarcane cultivars respectively grown over 11, 17, and 5% of the Louisiana sugarcane production area (Legendre and Gravois 2010). These cultivars have shown varying levels of resistance to *D. saccharalis* (White et al. 2008) and differences in shoot population and growth during the fall and spring were observed in our study. However, differences in *D. saccharalis* injury or infestations as affected by cultivar were only detected in early October 2007 when Ho 95-988 harbored greater (2.3-fold) infestations than L 99-226. In a previous study, Bessin and Reagan (1993) observed greater deadheart densities in CP 61-37 (*D. saccharalis* susceptible) than in CP 70-330 (resistant) during

the spring. Cultivar resistance to *D. saccharalis* has traditionally been determined using measures of mature stalk injury (% bored internodes), adult production (no. of moth exit holes in stalks), and tolerance to injury (% yield loss relative to % bored internodes) (Bessin et al. 1990b, White et al. 2008). When comparing 10 sugarcane cultivars with varying levels of resistance, White and Dunckelman (1989) found limited differences in *D. saccharalis* deadheart injury. However, the percentages of deadhearts were typically consistent with resistance rankings based on independent assessment of stalk injury levels in % bored internodes. Although differences in *D. saccharalis* resistance levels may not be observed when deadhearts occur, early in sugarcane phenology before the formation of elongated internodes, the potential of cultivars with increased resistance to minimize fall and spring borer infestations deserves further research.

Diatraea saccharalis infestations in newly planted sugarcane and stubble growth during the fall do not contribute directly to economic damage and have not been considered in management (Hensley 1971). *Diatraea saccharalis* late summer and fall populations are the source for overwintering borers, which will emerge in the spring the following year and cause economic damage. Our study showed that early planting and harvesting increase late summer and fall *D. saccharalis* populations, thus having the potential for increasing overwintering populations and subsequent economic damage. In areas where *D. saccharalis* is a severe problem, when susceptible cultivars are planted, or when insecticides cannot be applied, optimization of planting dates may help minimize *D. saccharalis* population build-up.

CHAPTER 5: POTENTIAL IMPACT OF MEXICAN RICE BORER NON-CROP HOSTS ON SUGARCANE IPM³

5.1. Introduction

The Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), is indigenous to Mexico and was first reported in 1980 in south Texas (Johnson 1984). This borer quickly became the most damaging insect pest of sugarcane, *Saccharum* spp. hybrids, in the Lower Rio Grande Valley of Texas, where it represents more than 95% of stem borer infestations (Legaspi et al. 1997a). After expanding its range in a northeast direction along the Gulf Coast (Reay-Jones et al. 2007c), *E. loftini* has also become an increasing problem for rice, *Oryza sativa* L., production in southeast Texas. *Eoreuma loftini* was detected in Louisiana for the first time in December 2008 (Hummel et al. 2008), representing a serious threat to the state's sugarcane and rice industries. The imminent establishment of *E. loftini* in Louisiana sugarcane producing areas encouraged proactive studies that integrate cultivar resistance, biorational insecticides, and irrigation-based population suppression to develop an effective management program (Reay-Jones et al. 2005d). Insecticides and cultivar resistance have also been studied in rice, which is also grown in sugarcane areas of Louisiana. In addition to crop hosts, Van Zwalunwenburg (1926) stated that *E. loftini* "attacks practically all the grasses large enough to afford it shelter within the stalk." Non-crop grasses may therefore play a role in the overwintering and build-up of *E. loftini* populations, and should be integrated into the development of new cultural practices for an improved pest management program. This chapter reports on initial studies with *E. loftini* non-crop hosts and discusses their possible importance in future sugarcane integrated pest management (IPM) for Louisiana.

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5.2. Material and Methods

5.2.1. Sentinel Plant Experiments

Two sentinel plant experiments were designed to compare *E. loftini* infestation development on selected non-crop grass species under natural infestations. Experiments were conducted in southeast Texas during 2006 and 2007 near Ganado (N 29.0267°, W 96.4394°) and Hankamer (N 29.8554°, W 94.5451°), respectively, where *E. loftini* populations naturally occur at high densities.

Five weed species that are abundant in or near sugarcane and rice fields and have the potential to host *E. loftini* populations were studied: johnsongrass [*Sorghum halepense* (L.) Persoon], Vasey's grass (*Paspalum urvillei* Steud.), Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitchc.], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R. D. Webster]. Rice (cultivar Cocodrie) served as a control. Seeds were obtained from Azlin Seed Service (Leland, MS), except for Vasey's grass seeds that were collected in Lafayette Parish, LA. Plants were grown in a greenhouse in 7.57 L pots, each containing eight (2006) or six (2007) evenly spaced plants. In mid-August, after growing for 2 mo under greenhouse conditions, the potted plants were placed in a rice field near a levee. For each plant species, six pots constituted a plot, and plots were arranged in a randomized complete block design with four blocks (1 replication per block). Plots were separated by 75-cm or 2-m spaces in 2006 and 2007, respectively. Plants remained in the pots, but pot bottoms were removed to facilitate better equalization with field moisture conditions.

In 2006, ten plants from each plot were randomly selected and cut at the base both 4 and 9 wk after transplanting. In 2007, 12 plants were sampled both 4 and 7 wk after transplanting.

Each tiller was measured and the number of leaves counted. Plants were observed for borer feeding signs and dissected for the presence of larvae and pupae.

Statistical analyses were performed using Proc GLIMMIX (SAS Institute 2008). Generalized linear mixed models (GLMMs) with an over-dispersion parameter were used to analyze the proportion of plants infested with *E. loftini* (binomial distribution) and *E. loftini* abundance as affected by plant species (Poisson distribution). Because the sugarcane borer, *Diatraea saccharalis* (F.), also infested sentinel plants in 2006, a GLMM with a binomial distribution was used to compare borer species composition as affected by the plant species. The Kenward-Roger adjustment for denominator degrees of freedom was used in all models to correct for inexact *F* distributions.

5.2.2. Adult Pheromone Trapping

Male *E. loftini* moths were continuously monitored to determine seasonal patterns of flight activity. From April 2007 to April 2009, monitoring was conducted at three sites in southeast Texas. Two standard universal pheromone traps were used at each site according to the method of Reay-Jones et al. (2007c). Traps were located near the Texas A&M AgriLife Research Center at Beaumont (N 30.0672°, W 94.2932°), and near Hankamer and Ganado where the two sentinel plant experiments were conducted. Traps were checked for *E. loftini* moths every 2-3 wk, and trap catches were estimated on a daily basis for each sampling period (Reay-Jones et al. 2007c).

5.3. Results

5.3.1. Sentinel Plant Experiments

The five grass weed species used as sentinel plants presented a diverse range of height, number of tillers, and leaf availability (Table 5.1). In 2006, 4 wk after transplanting to the field,

Table 5.1. Physical characteristics of grasses used in sentinel plant experiments, 4 and 9 wk (2006 experiment) and 4 and 7 wk (2007 experiment) after exposure to *E. loftini* natural infestations in Texas

2006 experiment	Rice		Johnsongrass		Vasey's grass		Amazon sprangletop		Barnyardgrass		Broadleaf signalgrass	
	4 wk	9 wk	4 wk	9 wk	4 wk	9 wk	4 wk	9 wk	4 wk	9 wk	4 wk	9 wk
Height (cm)	63.4	38.5	97.4	75.0	27.3	37.2	53.8	--	85.9	--	54.3	--
No. tillers / plant	1.8	3.2	1.7	1.3	2.6	5.5	1.5	--	1.9	--	3.3	--
No. total leaves / plant	9.9	10.2	10.3	3.4	10.2	18.3	9.5	--	12.7	--	22.2	--
No. green leaves / plant	5.1	6.4	5.4	2.6	9.0	12.9	1.9	--	4.9	--	7.4	--
2007 experiment												
	4 wk	7 wk	4 wk	7 wk	4 wk	7 wk	4 wk	7 wk	4 wk	7 wk	4 wk	7 wk
Height (cm)	62.1	56.8	84.3	85.4	50.0	66.0	67.5	59.8	59.4	55.8	56.6	56.7
No. tillers / plant	3.2	4.7	1.7	2.1	5.4	5.1	1.8	1.9	3.5	3.9	3.8	4.3
No. total leaves / plant	13.1	18.6	11.4	15.5	24.1	23.8	22.5	21.3	37.3	49.8	31.6	40.4
No. green leaves / plant	8.0	11.3	6.4	9.9	17.7	16.8	7.1	0.9	9.6	14.3	9.1	16.3

rice, johnsongrass, barnyardgrass, and broadleaf signalgrass were either heading or showing maturing flowerheads, whereas Amazon sprangletop was senescent. Vasey's grass, which had a slow germination rate, was still in a vegetative stage. Nine wk after transplanting, Amazon sprangletop, barnyardgrass, and broadleaf signalgrass, all three annual grasses, had completed their life cycles and had died. Rice was senescent whereas johnsongrass and Vasey's grass, two perennial grasses, showed a mixture of senescent and maturing leaf and stem tissues.

Each grass species harbored at least some stage of *E. loftini* larvae. In addition, the grasses also harbored *D. saccharalis* larvae. Depending on the grass species, *E. loftini* represented 48% to 73% and 74% to 93% of the recovered borers after 4 and 9 wk, respectively. However, the proportion of *E. loftini* versus *D. saccharalis* was not affected by the grass species ($F = 0.37$; $df = 5, 12.3$; $P = 0.857$ after 4 wk and $F = 0.66$; $df = 2, 4.6$; $P = 0.558$ after 9 wk). After 4 wk under natural infestations, there were differences in the proportion of plants infested with *E. loftini* ($F = 3.94$; $df = 5, 15$; $P = 0.018$) and the number of *E. loftini* per plant ($F = 3.45$; $df = 5, 18$; $P = 0.023$) as affected by the plant species. Amazon sprangletop was numerically the most infested species (Fig. 5.1 and 5.2). *Eoreuma loftini* fourth and larger instars represented 61.5% (LS mean) of the recovered immatures. *Eoreuma loftini* pupae and pupal casings, indicating completion of life cycle, represented 19.8% (LS mean) of the fourth instars and larger immatures, hereafter referred to as late instars. Infestations in rice and johnsongrass were not different from Amazon sprangletop although numerically trending lower. *Eoreuma loftini* late instars represented 19.4% and 5.6% (LS means) of the immatures recovered in rice and johnsongrass, respectively, with no pupae observed. Broadleaf signalgrass harbored less infestation compared to Amazon sprangletop, but was not different from the other grasses. *Eoreuma loftini* late instars represented 25% (LS mean) of the immatures recovered from

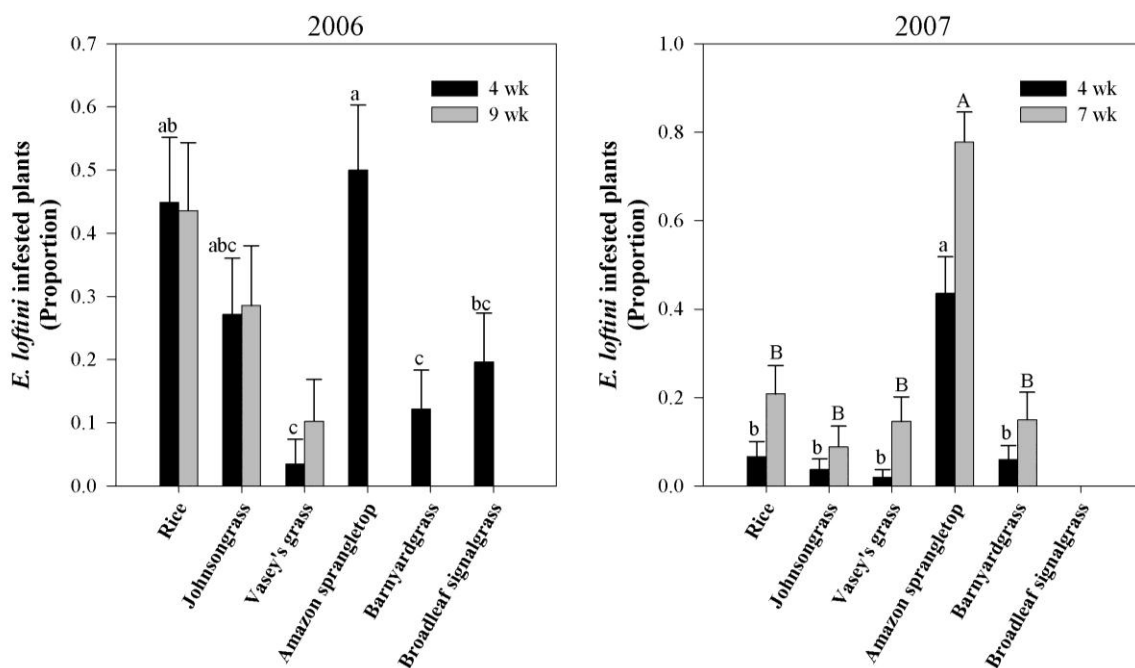


Fig. 5.1. Proportion of plants (LS means) with *E. loftini* infestations in sentinel plant experiments conducted in 2006 and 2007 in Texas. Bars with by the same letter (lower case 4 wk, upper case 9 or 7 wk) are not different (LSD, $\alpha = 0.05$). Letters were not included when all bars were not different. Error bars represent + SE

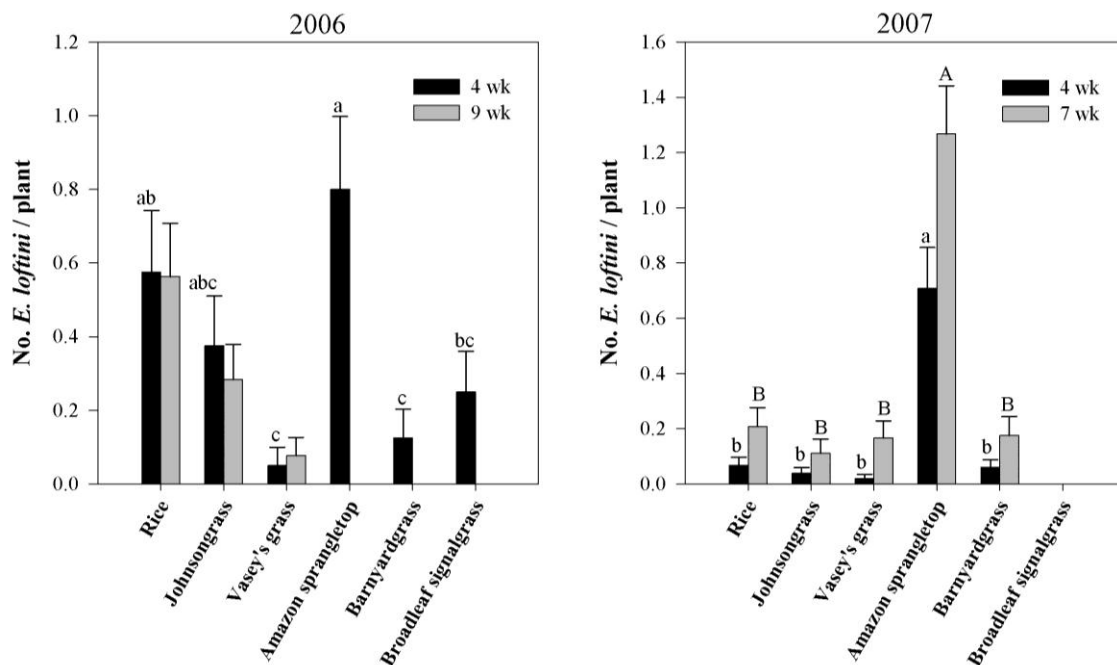


Fig. 5.2. Number of *E. loftini* (LS means) per plant in sentinel plant experiments conducted in 2006 and 2007 in Texas. Bars with by the same letter (lower case 4 wk, upper case 9 or 7 wk) are not different (LSD, $\alpha = 0.05$). Letters were not included when all bars were not different. Error bars represent + SE

broadleaf signalgrass, with one pupa observed. However, this pupa was in a folded flag leaf, suggesting that the original larvae possibly came from another plant. Barnyardgrass and Vasey's grass harbored the lowest *E. loftini* infestations (Fig. 5.1 and 5.2). Pupae were not found in barnyardgrass, however; 12.5% (LS mean) of the recovered immatures were late instars. No late instars were recovered from Vasey's grass. Five wk later, there were trends ($F = 2.62$; $df = 2, 9$; $P = 0.127$) for a greater proportion of *E. loftini* infested rice plants, in comparison to johnsongrass and Vasey's grass plants (Fig. 5.1). When considering the overall number of *E. loftini* per plant, rice also showed a strong trend ($F = 5.00$; $df = 2, 5.7$; $P = 0.056$) for greater borer densities (Fig. 5.2). In rice, johnsongrass, and Vasey's grass, pupae and pupal casings represented respectively 60.4%, 22.5%, and 12.5% (LS means) of the recovered *E. loftini*, indicating completion of the life cycle.

In 2007, 4 wk after transplanting to the field, all plants were either heading or had maturing flowerheads. Seven wk after transplanting, all plants exhibited maturing flowerheads, except Amazon sprangletop, which was senescent. Almost exclusively *E. loftini* infested the sentinel plants. However, three *D. saccharalis* larvae were recovered from Amazon sprangletop plants collected from the same plot. All grasses except broadleaf signalgrass were infested with *E. loftini* (Fig. 5.1 and 5.2). The proportion of plants infested after 4 wk ($F = 10.40$; $df = 5, 15.1$; $P < 0.001$) and 7 wk ($F = 8.83$; $df = 5, 18$; $P < 0.001$) changed with the plant species, as well as the number of *E. loftini* per plant ($F = 20.61$; $df = 5, 14.8$; $P < 0.001$ after 4 wk and $F = 15.02$; $df = 5, 18$; $P < 0.001$ after 7 wk). Amazon sprangletop harbored the highest *E. loftini* infestations (Fig. 5.1 and 5.2). Late instars were found only in Amazon sprangletop, representing 25% (LS mean) of the larvae collected. No pupae were recovered after 4 wk in the field. Three wk later, the late instars observed in Amazon sprangletop, rice, barnyardgrass, and Vasey's grass

represented 59.1%, 31.3%, 10% and 6.3% (LS means) of the recovered *E. loftini*. Only Amazon sprangletop and rice had allowed completion of *E. loftini* life cycle, with five and one pupae or pupal casings recovered, respectively representing 13.8% and 8.3% of the *E. loftini* late instars found in each grass.

5.3.2. Adult Pheromone Trapping

Pheromone trapping showed that moth flight activity reached its peak between September and November while it was at a minimum between December and February (Fig. 5.3). The highest *E. loftini* moth numbers were caught from the Hankamer site with 72.9 moths/trap/d for the 2 November 2008 sampling period. An early spring flight activity peak was recorded at the three trapping sites in March 2009. For the 16 March sampling period, 25.8 moths/trap/d were collected near Beaumont. For the Hankamer and Ganado sites, trap catches were 27.2 moths/trap/d for the 22 March period and 23.6 moths/trap/d for the 7 March period, respectively.

At the Beaumont site, *E. loftini* moths were not caught over more than two subsequent samplings from 23 December 2007 to 10 March 2008. At the Hankamer site, *E. loftini* moths were not caught over more than two subsequent samplings from 21 January 2008 to 11 February 2008. During the winter from 2008 to 2009, there were no two subsequent dates with zero catches at the Beaumont and Hankamer sites. Further south near Ganado, although trap catches were reduced somewhat in December and January, *E. loftini* moths were active all year long with no two subsequent dates of zero catches.

5.4. Discussion

The impacts on arthropod population dynamics of non-crop plants occurring in an agroecosystem are complex and far from following a general principle (Norris and Kogan 2005). Non-crop plants may offer shelter for predators, and both shelter and food for their prey,

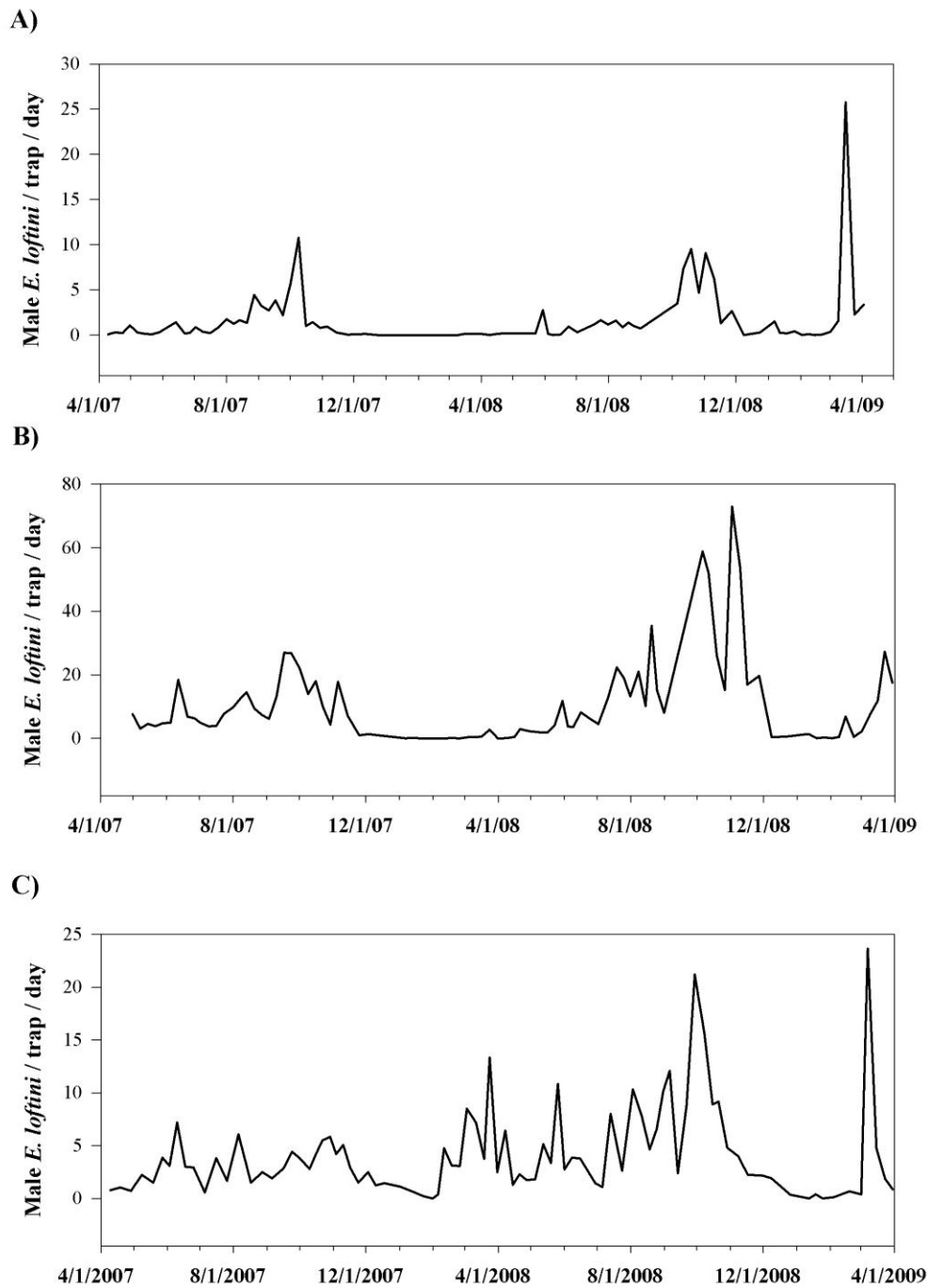


Fig. 5.3. Male *E. loftini* pheromone trap catches estimated on a daily basis near (A) Beaumont, (B) Hankamer, and (C) Ganado, Texas, April 2007-April 2009

increasing natural enemy density and subsequently decreasing pest populations (Letourneau 1987, Russell 1989). Conversely, non-crop plants may also serve as hosts and emit host-finding stimuli for crop pests, increasing pest populations (Karban 1997, Tindall et al. 2004). Our sentinel plant experiments showed that non-crop grasses could host *E. loftini*. Additional sampling of non-crop habitats near southeast Texas rice fields in February yielded *E. loftini* densities attaining as many as six immatures per m² (Chapter 6).

A plant is a host if both herbivore feeding and completion of the herbivore life cycle occur. Amazon sprangletop, a weed in Louisiana rice fields, is a highly suitable host. Because *D. saccharalis* injury to rice is higher in plots surrounded by Amazon sprangletop (Tindall 2004), this grass may also increase *E. loftini* infestations in surrounding areas. With no strong evidence of *E. loftini* completing its life cycle in broadleaf signalgrass and barnyardgrass, two common weeds in and near rice fields, the contribution of these grasses to *E. loftini* population pressure seems small. Plant morphological (e.g., pubescence, stem hardness and diameter, abundance of dry leaves) and biochemical (e.g., primary metabolites, allelochemicals) factors affect stem borer oviposition preference and larval performance (Martin et al. 1975, Sosa 1990, Meagher et al. 1996a, Reay-Jones et al. 2007b). Among other factors, the relatively smaller stem diameter of broadleaf signalgrass and barnyardgrass likely contributes to the lack of suitability as a host for *E. loftini*.

Plant availability over time also plays a major role in the use of non-crop grasses as hosts by *E. loftini*. Johnsongrass, a ubiquitous grass in weedy areas and sugarcane fields, was infested with *E. loftini* in both sentinel plant experiments and winter samplings of non-crop habitats (Chapter 6). With all borer life stages recovered and infestations not differing from those in rice in the sentinel plant experiments, johnsongrass is certainly a primary non-crop host. Bynum et al.

(1938) concluded that if not mowed often, johnsongrass could provide overwintering shelter for *D. saccharalis* and would be a source for spring infestations in Louisiana sugarcane. Another common perennial grass in weedy areas, Vasey's grass, was heavily infested in samplings of non-crop habitats during the winter (Chapter 6), whereas not particularly infested in the sentinel plant experiments. From these observations, Vasey's grass may not be a preferred host although suitable. Vasey's grass plants grow large over the years and offer live green material during the winter when other grasses are dry or too small (e.g., johnsongrass). Despite reduced numbers during the winter, *E. loftini* adults fly during any season. The difference in plant availability may therefore explain *E. loftini* aggregation in Vasey's grass during the winter; hence, Vasey's grass is certainly a primary non-crop host.

Our studies were conducted in southeast Texas agroecosystems where rice is a dominant crop. Results suggest that non-crop hosts could play a role in *E. loftini* population dynamics. Weeds differ in their life cycles (annual vs. perennial), timing of seasonal development, and habitat (crop fields vs. crop field margins, roadsides, ditches, or canal banks). Thus, the relative importance of each non-crop host species may change with time of the year, geographical area, and the dominant crop. The manipulation of *E. loftini* non-crop sources may decrease a significant proportion of areawide populations, decreasing infestations in sugarcane fields. Thus, our studies warrant a better characterization of the influence of non-crop hosts as *E. loftini* sources in Louisiana sugarcane. Research reported in the next two chapters includes periodical non-crop habitat sampling and *E. loftini* oviposition preference and larval performance studies. Our ultimate goal is to incorporate findings from studies reported in this dissertation project and ongoing research into a model that will simulate different weed management strategies (e.g., mowing, biorational insecticide applications) and predict their impact on *E. loftini* areawide populations, thereby improving the overall sugarcane area IPM.

CHAPTER 6: SEASONAL INFESTATIONS OF TWO STEM BORERS (LEPIDOPTERA: CRAMBIDAE) IN NON-CROP GRASSES OF GULF COAST RICE AGROECOSYSTEMS⁴

6.1. Introduction

Eoreuma loftini (Dyar) and *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) are stem boring pests of sugarcane (hybrids of *Saccharum* spp.), rice (*Oryza sativa* L.), corn (*Zea mays* L.), and sorghum [*Sorghum bicolor* (L.) Moench] crops in the Gulf Coast region (Long and Hensley 1972, Johnson 1984). While *D. saccharalis* has been established in the southeastern United States since the 1850s (Stubbs and Morgan 1902), *E. loftini* has expanded its range in a northeasterly direction since its first detection in south Texas in 1980 (Reay-Jones et al. 2007c). *Eoreuma loftini* was reported in 2008 for the first time in Louisiana (Hummel et al. 2010), where annual economic losses in sugarcane and rice may become as severe as \$250 million within the next decades (Reay-Jones et al. 2008).

In addition to crop hosts, Van Zwalunwenburg (1926) observed that *E. loftini* “attacks practically all the grasses large enough to afford it shelter within the stalk.” *Eoreuma loftini* has been collected from numerous grasses (Poaceae), *Canna* spp. (Cannaceae), and bulrush (Cyperaceae: *Scirpus validus* Vahl) (Osborn and Phillips 1946, Johnson 1984, Showler et al. 2011). *Diatraea saccharalis* larvae also feed on a range of non-crop grasses comparable to that reported for *E. loftini* (Jones and Bradley 1924, Holloway et al. 1928, Box 1956, Bessin and Reagan 1990). Beuzelin et al. (2010b), using potted sentinel plants grown under natural infestations, confirmed that a number of Gulf Coast region non-crop grasses were hosts for both *E. loftini* and *D. saccharalis*. Amazon sprangletop [*Leptochloa panicoides* (Presl) Hitch], a common weed in rice fields, was a highly suitable host, harboring the highest stem borer

⁴ Submitted for publication in Environmental Entomology, MS # EN-11-044 Version 1

infestations with >75% of the plants infested with at least one larva. Johnsongrass [*Sorghum halepense* (L.) Pers.] and Vasey's grass (*Paspalum urvillei* Steud.), two ubiquitous perennial grasses, also supported complete larval development of both species. In contrast, broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], a common weed near rice fields, proved to be a poor stem borer host (Beuzelin et al. 2010b, Showler et al. 2011).

The effects of vegetation diversity on arthropod population dynamics in agroecosystems are complex and variable (Andow 1991, Norris and Kogan 2005). Nearby plants may increase habitat availability for predators and offer additional shelter and food for their prey, thus increasing natural enemy density and subsequently decreasing insect pest populations (Letourneau 1987, Russell 1989). Conversely, nearby plants may increase plant host availability and release additional host-finding stimuli for insect pests, thus enhancing pest populations (Karban 1997, Tindall et al. 2004). Previous studies have suggested that non-crop hosts could play a key role in *E. loftini* and *D. saccharalis* population dynamics in Gulf Coast agroecosystems (Beuzelin et al. 2010b, Showler et al. 2011). However, the quantification of non-crop host presence and use has been limited, especially when crop hosts are absent or too young to sustain stem borer development. In this study, surveys were conducted to quantify the seasonal abundance of *E. loftini*, *D. saccharalis*, and their non-crop hosts in field margins and surrounding habitats of Texas rice agroecosystems.

6.2. Materials and Methods

6.2.1. Transect Sampling in Non-Crop Habitats

Three farms were surveyed in the Texas Gulf Coast rice production area (Jefferson County, N 30.059°, W 94.279°; Chambers County, N 29.855°, W 94.544°; and Jackson County, N 29.027°, W 96.439°). These farms were sampled every 6-8 wk for 2 yr (April 2007-February

2008, April 2008-February 2009). For each year, two transects were located along non-cultivated field margins, roadsides, or ditches on each farm. Transects averaged 564 ± 63 (SE) m in length and were within 250-500 m of the closest rice fields. On each sampling date (Fig. 6.1), three representative locations per transect were sampled, with three 1-m² quadrats randomly selected within 10 m of the center of each location. If sections of transects were mowed by rice producers during the growing season (March-August), they were excluded from sampling for at least two consecutive sampling dates. If sections were mowed during the postseason or winter (when plant growth is the slowest), they were permanently excluded from sampling.

For each quadrat, all graminoids (grass-like plants) were cut at the soil surface level and placed in 50-L plastic bags. Bags were stored at the Texas A&M AgriLife Research and Extension Center at Beaumont, TX, in a cold room at 13-15°C and processed within 1 wk. Non-crop graminoids present in each quadrat were identified to genus or species, and their relative abundance was visually estimated per volume of sampled plant material. The number of tillers for each graminoid was recorded (except for the 1st and 2nd samplings). During the second year of the study (April 2008-February 2009), average tiller size (from base to farthest tip) was determined for each graminoid in each quadrat from all (if tillers ≤ 4) or four randomly selected tillers. Average tiller stem diameter (as measured ≈ 1 cm below the 1st apparent node, or ≈ 3 cm above the cut if no node present) was also determined. For tillers with flattened stems, the average between the major and minor stem diameters were recorded. During the second year of the study, plant phenology was determined visually as the proportion of plant material that was vegetatively growing, flowering, mature, senescent, and dead.

All graminoids collected from the quadrats were examined for stem borer feeding injury. When injury was observed, plants were dissected to recover *E. loftini* and *D. saccharalis*

immatures. The size of larvae was visually determined, with small, medium-sized, and large larvae corresponding approximately to first and second, third, and fourth and fifth instars, respectively. Dependent on the number of borers recovered, 10 to 60 randomly selected *E. loftini* and *D. saccharalis* immatures were reared on artificial diet (Southland Product Inc., Lake Village, AR) until adult eclosion to confirm species identification.

6.2.2. Transect Sampling in Rice Habitats

During the early April sampling date of each year of the study, one fallowed rice field adjacent to non-crop habitats was sampled to verify whether old rice stubble could host *E. loftini* and *D. saccharalis*. In addition, one adjacent rice field planted between March and May was sampled in early April, late May, and late June to verify whether newly planted rice could host stem borers. For each rice field, one transect was drawn and five (2007) or three (2008) sampling zones with three 1-m² quadrats in each were sampled for stem borer injury and immature presence.

6.2.3. Adult Stem Borer Trapping

Eoreuma loftini and *D. saccharalis* moths were trapped on each farm near the center of each non-crop habitat transect for 7 to 14 d after transect sampling during the spring, summer, and fall. Following the December and February transect sampling of non-crop habitats, moth trapping averaged 33 and 15 d, respectively, because of reduced accessibility to trapping locations. Two traps per transect, one for *E. loftini* and one for *D. saccharalis*, were positioned approximately 10 m apart and placed 1.5 m above the soil surface on a metal pole. Bucket traps (Unitrap, Great Lakes IPM, Vestaburg, MI) were used for *E. loftini* moth monitoring. Each trap was baited with a synthetic female *E. loftini* sex pheromone lure (Luresept, Hercon Environmental, Emigsville, PA) and contained an insecticidal strip (Vaportape II, Hercon

Environmental, Emigsville, PA). Sticky wing traps (Pherocon 1C Trap, Trécé Inc., Adair, OK) were used for *D. saccharalis* moth monitoring. Each trap was baited with two *D. saccharalis* female pupae nearing adult eclosion. *Diatraea saccharalis* female pupae from laboratory rearing were provided by the USDA ARS Sugarcane Research Unit, Houma, LA (1st year of the study) and the LSU AgCenter Rice Entomology Laboratory, Baton Rouge, LA (2nd year of the study). Trap catches were adjusted by the length of the sampling period to express moth abundance on a moths per trap per day basis.

6.2.3. Data Analyses

All univariate statistical analyses were conducted using Proc GLIMMIX (SAS Institute 2008). The Kenward-Roger adjustment for denominator degrees of freedom was used in all models to correct for inexact *F* distributions. Unless stated otherwise, least square means \pm standard errors from the LSMEANS statement output (Proc GLIMMIX, SAS Institute 2008) are reported. When significant fixed effects were detected ($P < 0.05$), Tukey's HSD ($\alpha = 0.05$) was used to assist in the interpretation of observed patterns and differences in least square means. *Eoreuma loftini* and *D. saccharalis* infestations (no. immatures per m²) were compared using univariate mixed models with year, date, and year \times date as fixed effects. Farm, farm \times year, transect / farm \times year, transect \times date / farm \times year, and location / transect \times date / farm \times year were random effects.

Relative abundance was recorded simultaneously for numerous graminoids from the same observation units (i.e., quadrat). Thus, prior to univariate analyses, multivariate analyses including the 12 most prevalent graminoids (Table 6.1) were conducted using Proc GLM (SAS Institute 2008) with a MANOVA statement. Multivariate and univariate analyses included the same fixed and random effects as for stem borer infestation comparisons. Graminoid tiller

Table 6.1. Statistical comparisons for abundance and size estimates of 12 grasses commonly found in non-crop habitats adjacent to rice fields, Texas, 2007-2009

Plant		Relative abundance			Tiller density			Tiller size	Tiller stem diameter
		Year	Date	Year \times Date	Year	Date	Year \times Date	Date	Date
Johnsongrass	<i>F</i>	11.28	1.79	1.07	4.76	3.50	6.13	11.73	1.15
	df	1, 2.0	6, 227.2	6, 227.2	1, 2.2	6, 194.5	4, 194.6	6, 29.4	6, 22.9
	<i>P</i>	0.078	0.103	0.383	0.148	0.003	<0.001	<0.001	0.365
Vasey's grass	<i>F</i>	1.59	1.96	1.58	0.60	1.31	0.45	18.93	2.27
	df	1, 2.0	6, 227	6, 227	1, 2.4	6, 194.2	4, 194.2	6, 22.1	6, 56.7
	<i>P</i>	0.335	0.073	0.153	0.507	0.255	0.771	<0.001	0.049
Ryegrass	<i>F</i>	3.25	10.41	2.46	0.02	7.76	0.04	12.32	1.55
	df	1, 9.9	6, 56.5	6, 56.5	1, 17.4	6, 628.1	4, 628.1	3, 25.6	3, 3.38
	<i>P</i>	0.102	<0.001	0.035	0.877	<0.001	0.997	<0.001	0.339
Brome	<i>F</i>	0.01	8.55	0.47	0.00	6.09	0.01	7.06	4.02
	df	1, 4.0	6, 65.2	6, 65.2	1, 4.9	6, 195.6	4, 195.6	3, 4.6	3, 6.9
	<i>P</i>	0.938	<0.001	0.830	0.947	<0.001	1.000	0.035	0.060
Canarygrass	<i>F</i>	0.26	4.10	0.15	0.00	1.91	0.00	6.48	0.62
	df	1, 235	6, 235	6, 235	1, 2.4	6, 195.8	4, 195.8	1, 8.8	1, 1.7
	<i>P</i>	0.614	0.001	0.990	0.993	0.081	1.000	0.034	0.526
Angleton bluestem	<i>F</i>	0.95	2.51	0.51	0.98	1.40	0.53	0.46	2.96
	df	1, 2.0	6, 60.1	6, 60.1	1, 2.1	6, 55.9	6, 55.9	6, 3.2	6, 3.7
	<i>P</i>	0.433	0.031	0.798	0.420	0.232	0.716	0.811	0.170
Caucasian bluestem	<i>F</i>	0.27	1.51	0.57	0.16	0.80	0.82	0.69	0.38
	df	1, 7.9	6, 57.4	6, 57.4	1, 8.1	6, 193.6	4, 193.6	3, 2.5	3, 3.0
	<i>P</i>	0.620	0.191	0.754	0.700	0.573	0.512	0.625	0.774

Table 6.1. Continued

Plant	Relative abundance				Tiller density			Tiller size	Tiller stem diameter
		Year	Date	Year \times Date	Year	Date	Year \times Date	Date	Date
Hairy crabgrass	<i>F</i>	1.28	3.41	0.93	1.70	1.96	1.24	1.80	1.58
	df	1, 10.0	6, 60.2	6, 60.2	1, 10.1	6, 49.0	4, 49.0	4, 11.2	4, 12.8
	<i>P</i>	0.284	0.006	0.482	0.221	0.089	0.308	0.199	0.239
Jungle rice	<i>F</i>	0.29	1.52	1.90	0.53	1.00	2.23	2.28	4.86
	df	1, 10.0	6, 60.2	6, 60.2	1, 10.4	6, 47.0	4, 47.0	1, 1	1, 4.5
	<i>P</i>	0.461	0.187	0.095	0.484	0.484	0.080	0.372	0.085
Longtom	<i>F</i>	0.34	1.17	1.37	0.01	0.78	1.46	1.80	0.22
	df	1, 4.0	6, 227	6, 227	1, 8.3	6, 193.3	4, 193.3	4, 12	4, 9.9
	<i>P</i>	0.589	0.323	0.228	0.920	0.583	0.215	0.195	0.927
Torpedo grass	<i>F</i>	0.77	0.80	1.19	0.88	0.93	1.07	2.22	1.21
	df	1, 8.0	6, 60.1	6, 60.1	1, 8.0	6, 60.2	4, 60.2	5, 18	5, 5.3
	<i>P</i>	0.407	0.570	0.323	0.375	0.482	0.393	0.097	0.414
Non-identified perennial grass ^a	<i>F</i>	0.59	1.78	0.30	0.55	1.20	0.34	9.05	9.86
	df	1, 2	6, 60.2	6, 60.2	1, 2.1	6, 49.6	4, 49.6	5, 6.5	4, 14
	<i>P</i>	0.523	0.118	0.936	0.533	0.321	0.852	0.007	0.001

^a no reproductive parts and non-distinctive vegetative material

densities were compared using the same method as for plant relative abundance analyses. Tiller size and stem diameter, which were recorded during the second year of the study, were each compared using univariate mixed models with date as fixed effect and farm, transect / farm, transect \times date / farm, and location / date \times transect / farm as random effects.

For each of the six graminoids consistently infested with borers (Table 6.2), proportions of recovered *E. loftini* as affected by year and date were compared. By transect and sampling date, the proportion (%) of recovered *E. loftini* in a selected graminoid was computed as the sum of *E. loftini* collected from that selected plant divided by the sum of *E. loftini* collected from all plants. When *E. loftini* were not collected from a transect on a sampling date, proportions of recovered *E. loftini* were not computed. In addition, when a graminoid was not recorded from a transect, the proportion of recovered *E. loftini* was considered zero. A multivariate analysis including the six graminoids consistently infested with borers was conducted prior to univariate analyses. Fixed effects for the multivariate model (Proc GLM with MANOVA statement, SAS Institute 2008) were year, date, and year \times date while random effects were farm, farm \times year, and transect / farm \times year. Each univariate mixed model for each graminoid shared the same fixed and random effects as the multivariate model. For each of the two most prevalent graminoids consistently infested with *E. loftini*, the proportion (%) of recovered *E. loftini* per percent of plant relative abundance was determined. By transect and sampling date, it was computed as the proportion of recovered *E. loftini* in a selected graminoid divided by the average relative abundance for that selected plant. Only univariate analyses comparing proportions of recovered *E. loftini* per percent of plant relative abundance as affected by year and date were conducted, with the same model as for the proportion of recovered *E. loftini* analysis.

The proportion of recovered *D. saccharalis* and the proportion of recovered *D. saccharalis* per percent of plant relative abundance were computed using the same method as for *E. loftini*. Because *D. saccharalis* infestations were recovered almost exclusively from the two most prevalent graminoid species, only univariate analyses comparing year and date for these two plant species were conducted with the same model as for the proportion of recovered *E. loftini* analysis. *Eoreuma loftini* and *D. saccharalis* moth trap catches as affected by year and date were also compared using the same univariate mixed models.

Table 6.2. Statistical comparisons for *E. loftini* infestation recovered from six grasses commonly found in non-crop habitats adjacent to rice fields, Texas, 2007-2009

Plant		Proportion of recovered <i>E. loftini</i>		
		Year	Date	Year \times Date
Johnsongrass	<i>F</i>	9.67	4.99	0.56
	df	1, 8.4	6, 55.8	6, 55.7
	<i>P</i>	0.014	<0.001	0.761
Vasey's grass	<i>F</i>	0.81	5.88	1.03
	df	1, 2.0	6, 55.2	6, 55.1
	<i>P</i>	0.464	<0.001	0.418
Ryegrass	<i>F</i>	5.82	7.07	3.65
	df	1, 2.2	6, 61.7	6, 61.7
	<i>P</i>	0.126	<0.001	0.004
Brome	<i>F</i>	1.06	5.24	2.12
	df	1, 4.2	6, 61.4	6, 61.4
	<i>P</i>	0.360	<0.001	0.064
Canarygrass	<i>F</i>	2.62	1.44	1.44
	df	1, 7.0	6, 52.1	6, 52.1
	<i>P</i>	0.150	0.218	0.218
Angleton bluestem	<i>F</i>	0.13	1.57	1.22
	df	1, 63.1	6, 63.0	6, 63.0
	<i>P</i>	0.717	0.171	0.310

6.3. Results

6.3.1. *Eoreuma loftini* and *D. saccharalis* Infestations in Non-Crop Habitats

Eoreuma loftini larvae and pupae were recorded in non-crop habitats during each sampling date (Fig. 6.1A). There was a numerical trend ($F = 8.78$; $df = 1, 2.0$; $P = 0.097$) with 2.5-fold

greater *E. loftini* infestations in these habitats during the second year of the study than during the first year (4.01 ± 0.73 vs. 1.63 ± 0.73 borers per m^2). Infestations changed with date ($F = 2.52$; $df = 6, 60.2$; $P = 0.030$), increasing from early spring to late fall (Fig. 6.1A). The lowest *E. loftini* infestations were observed in April (1.23 ± 0.83 borers per m^2), while infestations were greater in October (3.1-fold) and December (3.2-fold). As shown by the non-significant year \times date interaction ($F = 1.42$; $df = 6, 60.2$, $P = 0.222$), differences in *E. loftini* infestations as affected by date did not change between the first and the second year of the study. For *D. saccharalis*, differences in infestations in non-crop habitats were not detected ($F = 1.51$; $df = 1, 2.0$; $P = 0.344$) between the first and second year (0.25 ± 0.08 and 0.11 ± 0.08 borers per m^2 , respectively) of the study (Fig. 6.1B). Although changes in *D. saccharalis* infestations were not detected among dates ($F = 1.67$; $df = 6, 66.2$; $P = 0.143$), infestations were high in October 2007 (0.94 ± 0.19 borers per m^2 , Fig. 6.1B) but not in October 2008, as evidenced by the year \times date interaction ($F = 2.39$; $df = 6, 66.2$; $P = 0.038$).

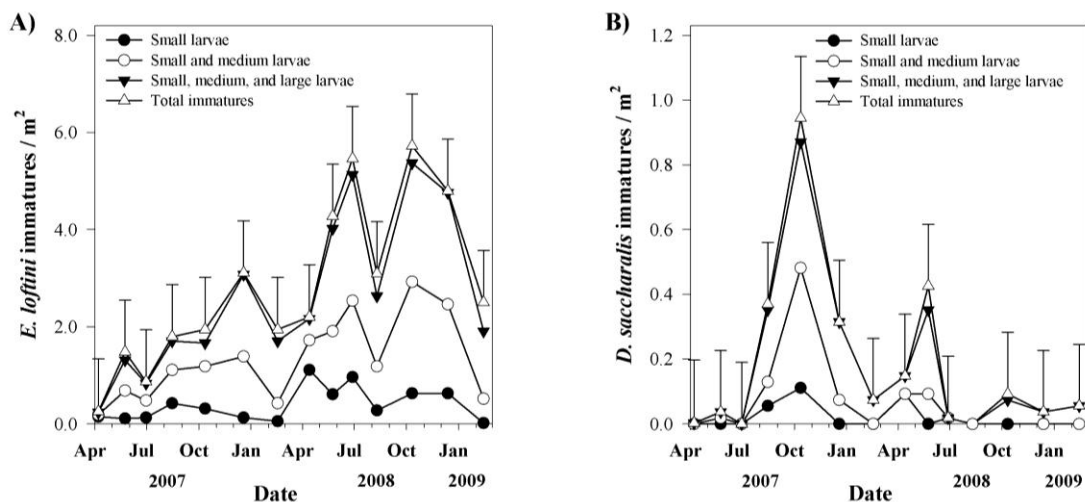


Fig. 6.1. (A) *E. loftini* and (B) *D. saccharalis* immature infestations (LS means) in non-crop habitats surrounding rice fields in Texas, 2007-2009. Error bars represent + SE for total immature LS means

6.3.2. Graminoid Composition in Non-Crop Habitats

The 12 most prevalent graminoids surrounding rice fields in Texas are listed in Table 6.1. The multivariate analysis shows that the relative abundance of at least one of these graminoids changed with date (Wilks' Lambda = 0.062; $F = 2.02$, $df = 72, 218.0$; $P < 0.001$), but changes occurred to a different extent between the first and second year of the study (Wilks' Lambda = 0.219; $F = 1.53$; $df = 48, 152.3$; $P = 0.027$ for the year \times date interaction). In addition, multivariate analysis comparing tiller density showed that differences across dates occurred (Wilks' Lambda = 0.027; $F = 2.86$; $df = 72, 218.0$; $P < 0.001$) for at least one of the 12 graminoids. The year \times date interaction was not significant (Wilks' Lambda = 0.292; $F = 1.19$; $df = 48, 152.3$; $P = 0.210$). For both relative abundance and tiller density, the multivariate effect of year could not be tested because of an insufficient number of error degrees of freedom.

Johnsongrass was the most often encountered and abundant graminoid (Fig. 6.2). However, johnsongrass relative abundance did not differ across dates despite trends ($P \leq 0.1$, Table 6.1) for a minimum in April ($50.4 \pm 7.0\%$). Trends ($P \leq 0.1$, Table 6.1) for a greater relative abundance were also observed during the second year of the study (70.8 ± 6.2 vs. $51.9 \pm 6.2\%$). Tiller density (Fig. 6.2B) was affected by date (Table 6.1), with a maximum observed in August (44.8 ± 3.9 tillers per m^2). Johnsongrass size changed with date (Table 6.1) with the tallest tillers observed in October, and the shortest in February and April (Fig. 6.3A). In addition, johnsongrass stem diameter increased from the spring to the winter (Table 6.1; Fig. 6.3B). During the early spring, dead leafless tillers remaining from the previous year as well as young green vegetative growth with an occasional emerging flower were recorded (Fig. 6.4A). Flowering peaked between April and late June, and a mixture of vegetative, flowering, and mature tillers occurred between May and August (Fig. 6.4A). Mature johnsongrass showed aging

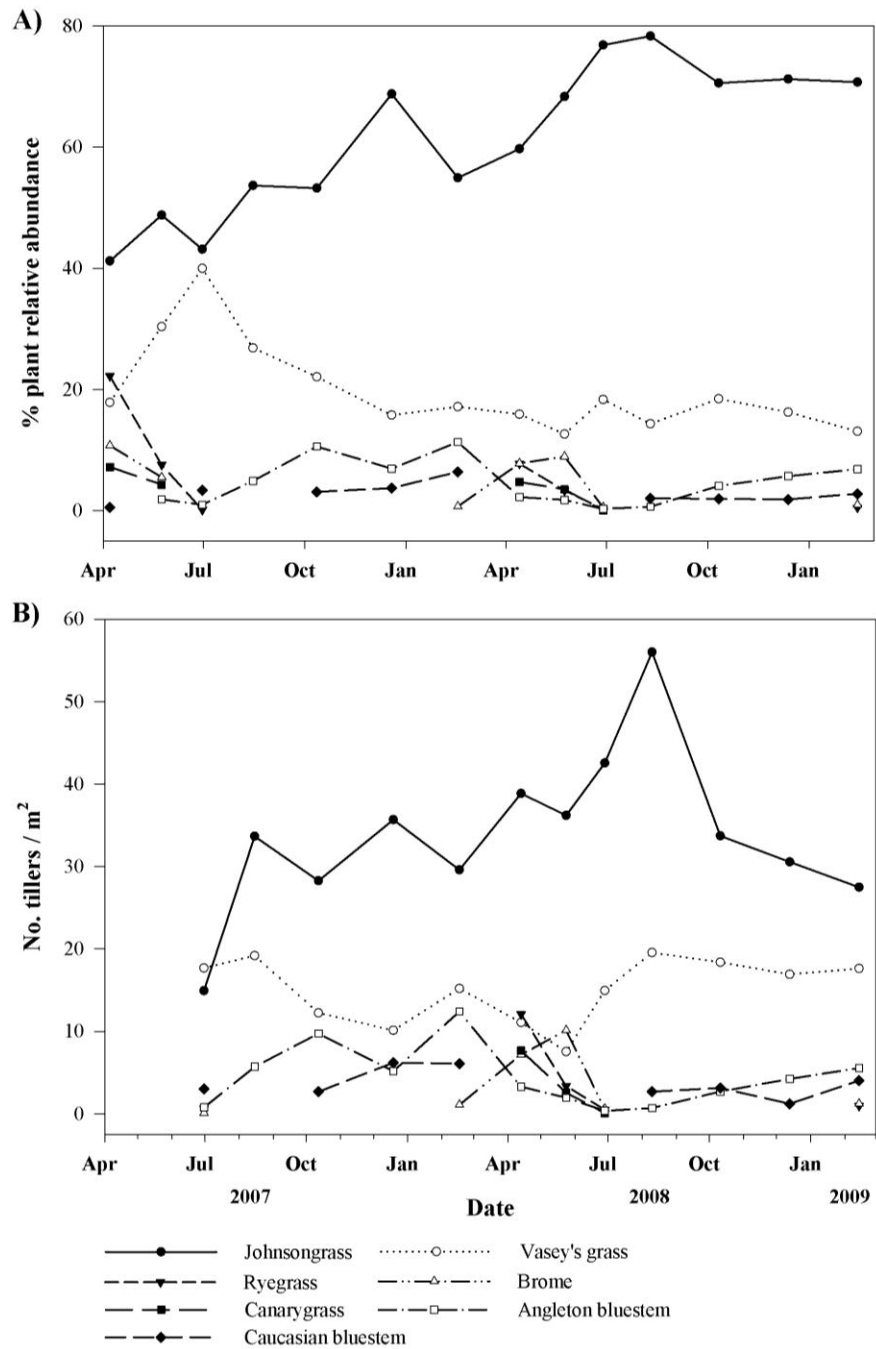


Fig. 6.2. (A) Relative abundance and (B) tiller density (LS means) for seven of the most commonly sampled grasses in non-crop habitats adjacent to rice fields in Texas, 2007-2009. When a grass did not occur, markers were not included on the figure

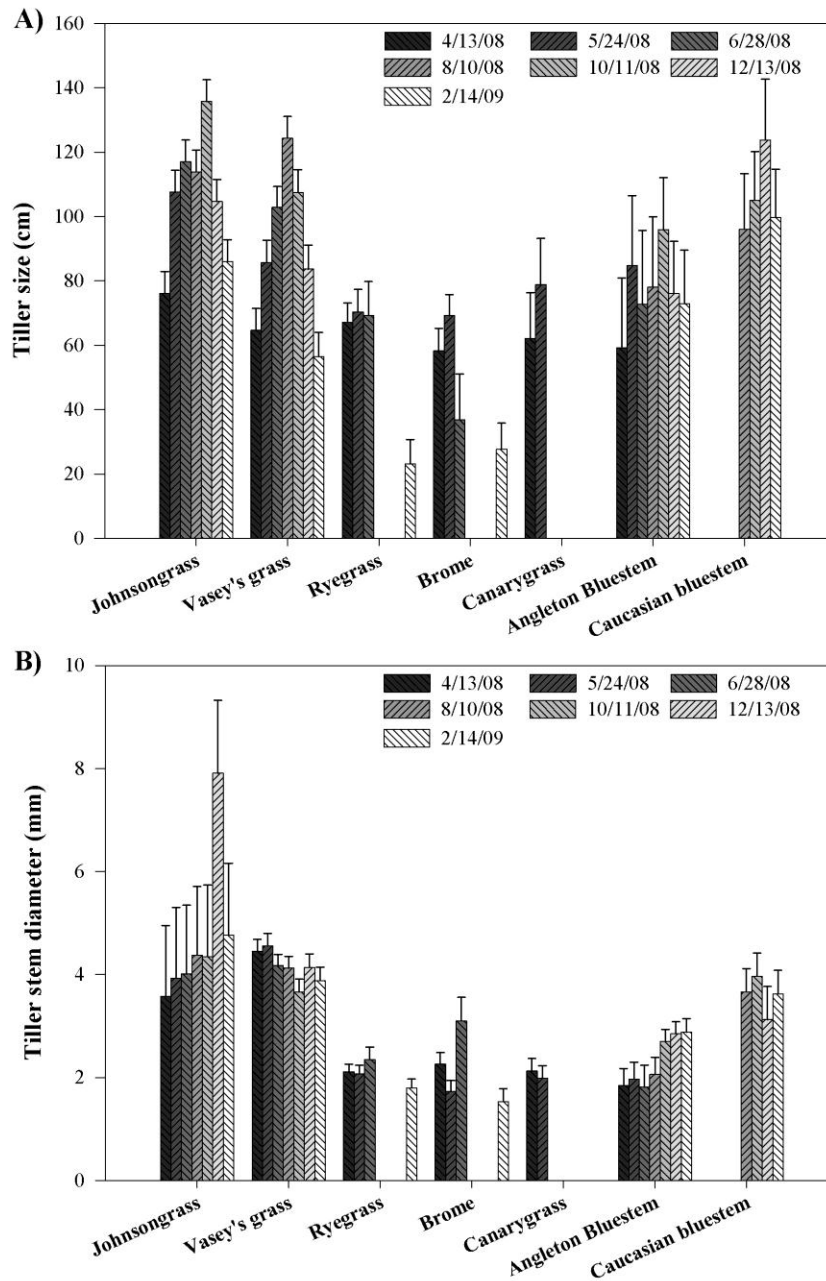


Fig. 6.3. (A) Tiller size and (B) stem diameter (LS means + SE) for seven of the most commonly sampled grasses in non-crop habitats adjacent to rice fields in Texas, 2008-2009

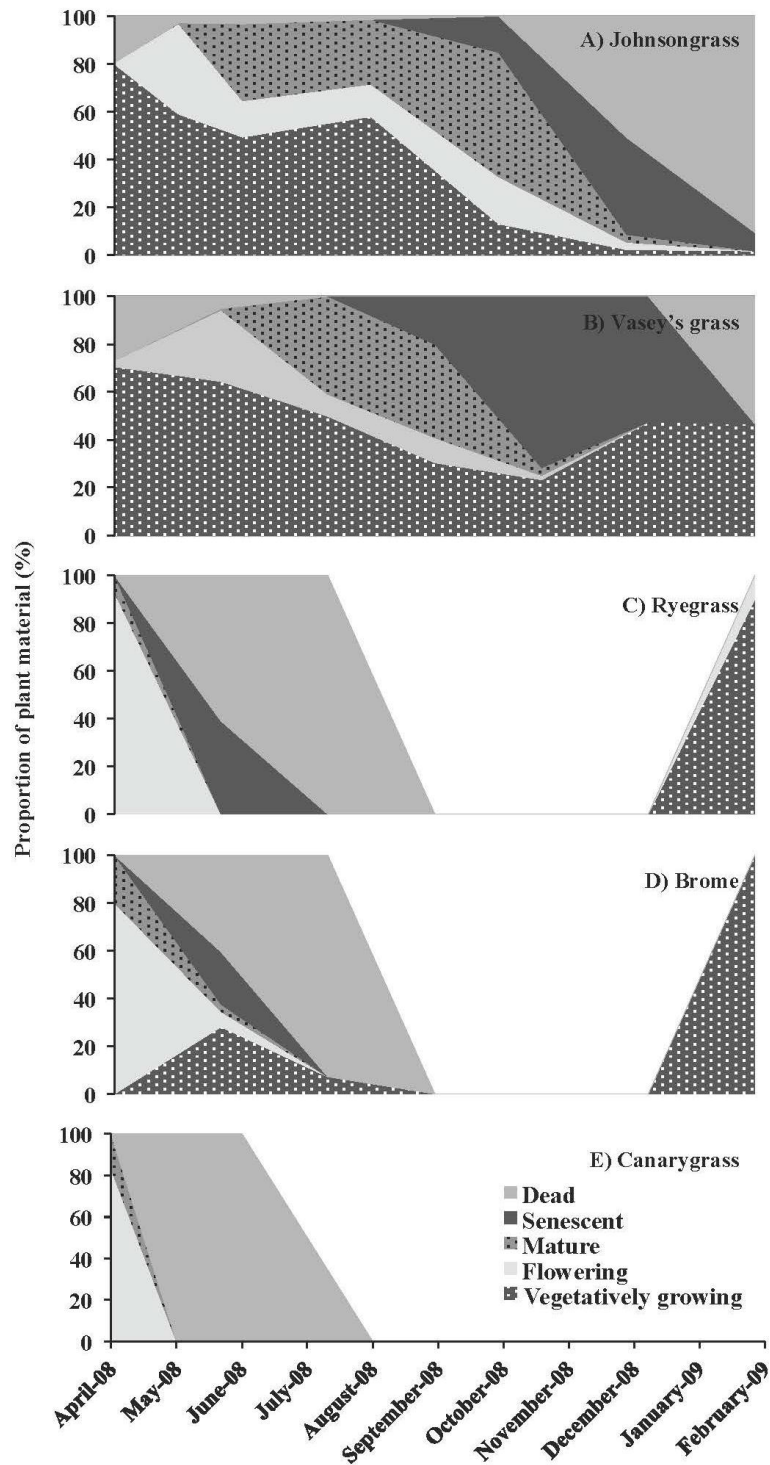


Fig. 6.4. Stem borer non-crop host phenology in habitats surrounding rice fields in Texas, 2008-2009

foliage and empty seed heads, but also green offshoots growing from nodal buds. During the fall, a majority of mature and senescing tillers were present; but vegetative and flowering johnsongrass was observed in areas mowed in the spring or summer. During the winter, a majority of tillers were dead or senescing. In addition, young vegetative tillers had emerged in February, with 0 to 14 tillers per m² averaging of 1.8 tillers per m² (Fig. 6.4A).

Vasey's grass was the second most prevalent graminoid adjacent to rice fields (Fig. 6.2). Although Vasey's grass relative abundance was not different among dates (Table 6.1), trends ($P \leq 0.1$) for a lower abundance in February and a greater abundance in late June (15.1 ± 6.0 vs. $29.1 \pm 6.0\%$, respectively) were observed. Differences in tiller densities between years and among dates were not detected (Table 6.1; Fig. 6.2B). During the early spring, Vasey's grass bunches exhibited dead plant material from earlier growth, green material in a vegetative stage, and a small proportion of flowering tillers (Fig. 6.4B). Flowering peaked in the spring, and during the summer, plants showed a mixture of vegetative, flowering, mature, and senescing tillers. The proportion of senescing tillers increased in the fall. In the winter, bunches of Vasey's grass were composed of dead and green vegetative tillers (Fig. 6.4B). Vasey's grass tillers were the tallest in August, 1.9 and 1.5-fold taller than in April and December, respectively (Table 6.1; Fig. 6.3A). Tiller stem diameter (Table 6.1) was larger in May than in October (1.2-fold, Fig. 6.3B).

Ryegrass (*Lolium* spp.), brome (*Bromus* spp.), and canarygrass (*Phalaris* spp.) are annual grasses that did not occur in August, October, or December. Relative abundance for ryegrass showed trends ($P \leq 0.1$, Table 6.1) for being greater (2.5-fold) during the first year (Fig. 6.2A). In addition, ryegrass relative abundance peaked in April (Fig. 6.2A). As shown by the year \times date interaction (Table 6.1), changes in relative abundance between April and May, and between

May and late June, occurred to a greater extent in 2007 (2.9-fold and 58.4-fold, respectively) than in 2008 (2.3-fold and 11.5-fold, respectively) (Fig. 6.2A). Ryegrass tillers occurred at greater densities in the early spring (April) than during the late winter (February) (Fig. 6.2B). Ryegrass tiller size differed with date (Table 6.1). Tillers measured ≈ 70 cm during the spring (Fig. 6.3A), and were the smallest in February (2.9-fold smaller than in April). Differences in ryegrass tiller stem diameter (Fig. 6.3B) were not detected (Table 6.1). Brome and canarygrass relative abundances were affected by date (Table 6.1), peaking in April and May (Fig. 6.2A). Brome tillers occurred at greater densities in February and April than in May (Fig. 6.2B). Canarygrass was not collected in February, and differences in tiller density from April to late June were not detected (Table 6.1). Similarly to ryegrass, brome tillers were the shortest in February (Fig. 6.3A). In addition, brome tillers collected in February showed a trend ($P \leq 0.1$, Table 6.1) for a smaller stem diameter (Fig. 6.3B). Canarygrass tillers collected in April were shorter (Table 6.1) than those sampled in May (1.3-fold, Fig. 6.3A); however, stem diameter did not change (Table 6.1; Fig. 6.3B). Ryegrass, brome, and canarygrass typically were flowering or mature in early April, senescent or dead in May, and dead in late June (Fig. 6.4). However, late brome growth in the spring appeared in the vegetative stage in May and June. In February, while young vegetative ryegrass and brome tillers were growing, canarygrass was not (Fig. 6.4).

Angleton bluestem [*Dichanthium aristatum* (Poir.) C.E. Hubbard] and Caucasian bluestem [*Bothriochloa bladhii* (Retz.) S.T. Blake] are two perennial grasses that occurred sporadically on the study farms, but were sometimes abundant where present. Differences in Angleton bluestem relative abundance were detected (Table 6.1), with relative abundance greater in the fall and winter than during the spring and summer (Fig. 6.2A). However, differences in tiller density (Fig. 6.2B), size (Fig. 6.3A), and stem diameter (Fig. 6.3B) were not detected (Table 6.1). For

Caucasian bluestem, differences in relative abundance (Fig. 6.2A), tiller density (Fig. 6.2B), size (Fig. 6.3A), and stem diameter (Fig. 6.3B) were not detected (Table 6.1). Angleton bluestem's phenology was similar to that of johnsongrass. Caucasian bluestem exhibited vegetative growth from the spring to the fall, senescent tillers with dry foliage in December, and both dead tillers and vegetative growth in February.

Hairy crabgrass [*Digitaria sanguinalis* (L.) Scop.] and jungle rice [*Echinochloa colona* (L.) Link] are two summer annual grasses that were found in non-crop habitats directly adjacent to rice fields during the summer and the fall. Hairy crabgrass relative abundance changed with date (Table 6.1), peaking between August and October, with a maximum of $4.7 \pm 1.1\%$ recorded in October 2007. However, only limited evidence for differences in tiller density was detected (Table 6.1), even with a maximum of 4.3 ± 1.3 tillers per m^2 (October 2007). When hairy crabgrass tillers were present, both size (34.2 ± 28.1 to 94.3 ± 14.2 cm) and stem diameter (2.1 ± 0.2 to 2.5 ± 0.1 mm) were not different among dates (Table 6.1). Similarly to hairy crabgrass, jungle rice does not grow in the spring, and plants were not collected in April and May. However, differences among dates in relative abundance and tiller density (with respective maxima of $3.7 \pm 0.7\%$ and 6.0 ± 1.3 tillers per m^2 in August 2007) were not detected (Table 6.1). When jungle rice tillers were present, differences in size (42.5 ± 5.6 to 49.5 ± 5.5 cm) were not detected, but there were trends ($P \leq 0.1$, Table 6.1) for a larger stem diameter in October compared to December (2.3 ± 0.2 and 1.6 ± 0.2 mm, respectively). Hairy crabgrass and jungle rice were vegetative early in the summer, flowering in August, and senescing in October. Only decaying tillers were observed in December.

A non-identified perennial grass with no reproductive parts and non-distinctive vegetative material was collected in wet areas of non-crop habitats surrounding rice fields. The relative

abundance and tiller density for this grass did not differ throughout the seasons (Table 6.1), with a maximum of $4.0 \pm 1.8\%$ (August 2007) and 9.9 ± 2.7 tillers per m^2 (June 2007), respectively. Tiller size and stem diameter changed with date (Table 6.1), with size increasing from spring to fall (31.3 ± 5.5 cm in April to 79.0 ± 7.8 cm in October) and stem diameter being larger in the spring (3.6 ± 0.2 mm in April) than during the summer and fall (2.3 ± 0.1 mm in June). In poorly drained areas, torpedo grass (*Panicum repens* L.) was also collected. Relative abundance and tiller density for torpedo grass were not different throughout the seasons (Table 6.1), with a maximum of $1.5 \pm 0.6\%$ (February 2009) and 3.6 ± 1.2 tillers per m^2 (December 2008), respectively. Whereas differences in tiller stem diameter (1.5 ± 0.2 to 1.9 ± 0.1 mm) were not detected (Table 6.1), there were trends ($P \leq 0.1$, Table 6.1) for shorter tillers in the spring than in the fall (34.0 ± 8.2 cm in April vs. 60.2 ± 6.7 cm in October).

Longtom (*Paspalum denticulatum* Trin.) was collected sporadically with relative abundance and tiller density reaching $2.3 \pm 0.7\%$ and 1.6 ± 0.6 tillers per m^2 , respectively, in June 2007 (Table 6.1). When longtom tillers were present, both their size (44.3 ± 13.1 to 72.9 ± 7.6 cm) and stem diameter (2.4 ± 0.4 to 2.8 ± 0.3 mm) did not differ among dates (Table 6.1). Other graminoids that were collected during this study included fall panicgrass (*Panicum dichotomiflorum* Michx.), longspike beardgrass [*Bothriochloa longipaniculata* (Gould) Allred & Gould], browntop signalgrass [*Urochloa fusca* (Sw.) B.F. Hansen & Wunderlin], bushy bluestem [*Andropogon glomeratus* (Walter) Britton et al.], Bermudagrass [*Cynodon dactylon* (L.) Pers.], dallisgrass (*Paspalum dilatatum* Poir.), flatsedge (Cyperaceae: *Cyperus* spp.), bristlegrass (*Setaria* spp.), and Nealley's sprangletop (*Leptochloa nealleyi* Vasey).

6.3.3. *Eoreuma loftini* Infestations in Non-Crop Plants

Multivariate analyses showed that for at least one of the six graminoids consistently infested with borers (Table 6.2), the proportion of recovered *E. loftini* differed with date (Wilks' Lambda

= 0.106; $F = 4.12$, $df = 36$, 222.3, $P < 0.001$). The year \times date interaction was significant (Wilks' Lambda = 0.252; $F = 2.28$; $df = 36$, 222.3; $P < 0.001$) although the multivariate effect of year could not be tested because of an insufficient number of error degrees of freedom.

The proportion of *E. loftini* recovered from johnsongrass differed among dates (Fig. 6.5A, Table 6.2), increasing from April to August (2.2-fold) and decreasing during the fall and winter (2.3-fold). In addition, the univariate analysis (Table 6.2) suggested that the proportion of *E. loftini* recovered from johnsongrass was greater (1.5-fold) during the second year of the study than during the first. During the winter, *E. loftini* infesting johnsongrass were observed near nodes or within 5 cm of the soil surface, where visibly live plant tissue was found inside stems. In addition, dead desiccated *E. loftini* larvae were observed during the February and early April sampling periods. The proportion of *E. loftini* recovered per percent of johnsongrass relative abundance (Fig. 6.5B) changed with date ($F = 4.59$; $df = 6$, 56.3; $P = 0.001$), following a pattern comparable to that of the proportion of recovered *E. loftini*. Throughout the seasons, the proportion of *E. loftini* recovered from Vasey's grass changed (Table 6.2), with an increase (3.3-fold) from April to late June, followed by a decrease (2.2-fold) in August and an increase (3.2-fold) during the fall and winter (Fig. 6.5A). The proportion of recovered *E. loftini* per percent of Vasey's grass relative abundance changed with date ($F = 7.70$; $df = 6$, 60; $P < 0.001$), peaking during the winter (Fig. 6.5B). At this time of the year, pupae were observed in dry sections of the plants while larvae fed within green vegetative tillers close to soil level. Ryegrass and brome harbored *E. loftini* during the spring in 2007 and 2008 (Fig. 6.5A), and one *E. loftini* larva was recovered from brome in February 2008. The proportion of *E. loftini* recovered from ryegrass in April was greater (6.1-fold) during the first year of the study than during the second (Table 6.2).

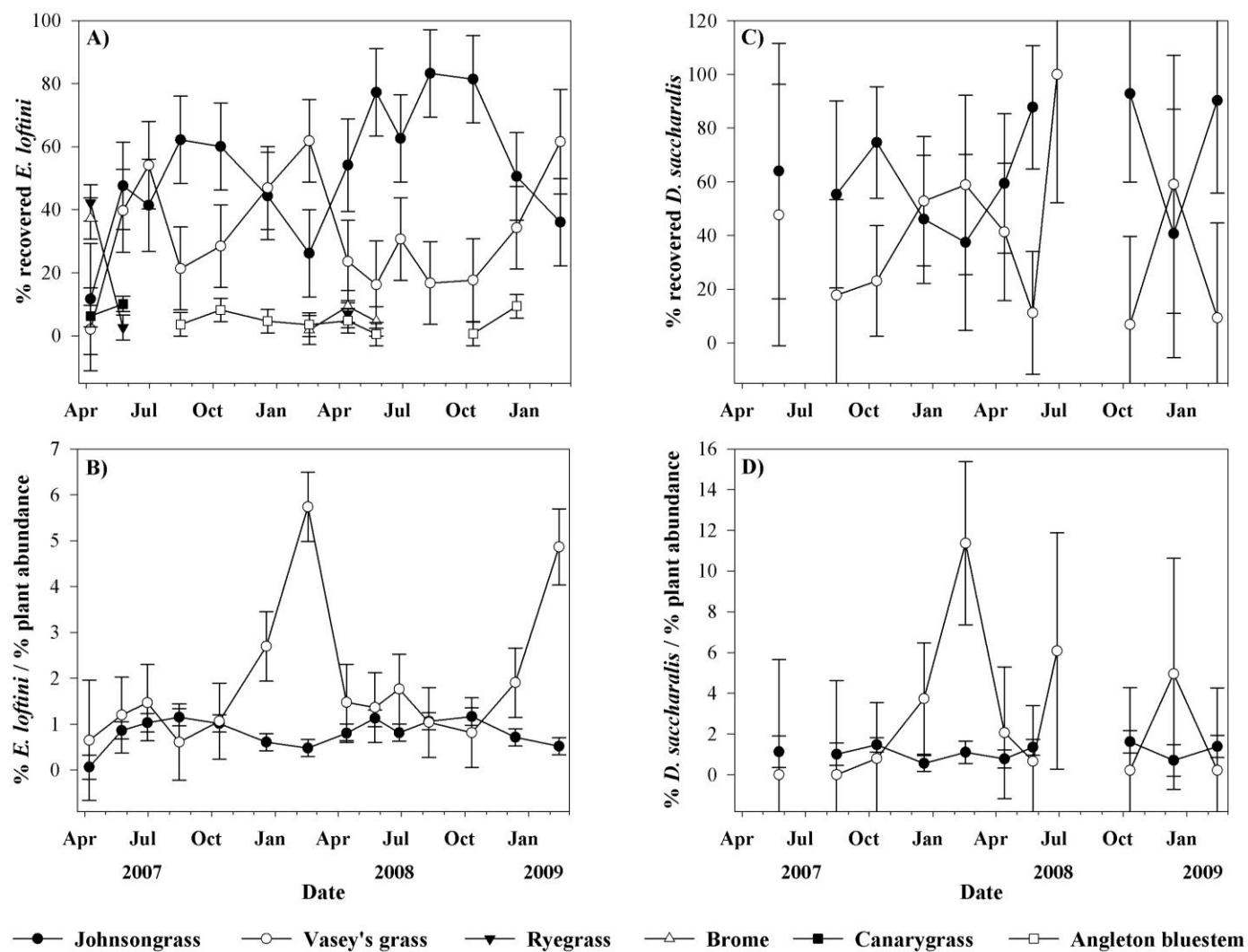


Fig. 6.5. Relative stem borer infestations (LS means \pm SE) in grasses growing in non-crop habitats adjacent to rice fields in Texas, 2007-2009. (A) Proportion of recovered *E. loftini* in six grasses. (B) Proportion of recovered *E. loftini* per percent johnsongrass and Vasey's grass abundance. (C) Proportion of recovered *D. saccharalis* in johnsongrass and Vasey's grass. (D) Proportion of recovered *D. saccharalis* per percent grass abundance. Markers were not included on the figure when borers were not recovered

A comparable trend ($P \leq 0.1$, Table 6.2) was observed for *E. loftini* recovered from brome (4.0-fold). *Eoreuma loftini* infestations in canarygrass were found only during the spring 2007 (Fig. 6.5A), but differences in proportions of recovered *E. loftini* were not detected among dates (Table 6.2). Angleton bluestem was infested with *E. loftini* all year (Fig. 6.5A). However, differences in proportions of *E. loftini* recovered from this perennial were not detected among dates (Table 6.2).

A total of 617 and 1,515 *E. loftini* immatures were recovered during the first and second years of the study, respectively. Ninety-six point one and 98.0% of these immatures infested the six graminoids addressed in the previous paragraph for the first and second years of the study, respectively. The remaining *E. loftini* immatures were recovered from 12 of the less abundant grasses and sedges (Table 6.3). *Eoreuma loftini* was not collected from torpedo grass, Bermudagrass, or bristlegrass.

6.3.4. *D. saccharalis* Infestations in Non-Crop Plants

Ninety-four and 42 *D. saccharalis* immatures were recovered during the first and second year of the study, respectively. These borers were collected almost exclusively from johnsongrass and Vasey's grass, which together harbored 94% and 100% of the infestations for the first and second year of the study, respectively. The remaining *D. saccharalis* larvae were collected from Angleton bluestem (4 larvae), jungle rice (1 larva), and browntop signalgrass (1 larva). Differences in proportions of *D. saccharalis* recovered from johnsongrass and proportions of *D. saccharalis* recovered per percent of johnsongrass relative abundance (Fig. 6.5) were not detected between the two years of the study ($F = 0.77$; $df = 1, 9.5$; $P = 0.403$ and $F = 0.26$; $df = 1, 16$; $P = 0.618$, respectively) and among dates ($F = 1.01$; $df = 6, 10.3$; $P = 0.467$ and $F = 1.08$; $df = 6, 16$; $P = 0.417$, respectively). In Vasey's grass, differences in proportions of recovered *D.*

Table 6.3. *Eoreuma loftini* larval infestations recovered from 12 grasses and sedges found sporadically in non-crop habitats adjacent to rice fields, Texas, 2007-2009

Plant	2007-2008		2008-2009	
	No. quadrats infested	No. <i>E. loftini</i> recovered	No. quadrats infested	No. <i>E. loftini</i> recovered
Caucasian bluestem	1 on 19 December 2007	1	0	0
	1 on 17 February 2008	2		
Hairy crabgrass	2 on 15 August 2007	2	1 on 11 October 2008	1
	1 on 19 December 2007	1		
	1 on 17 February 2008	1 ^a		
Jungle rice	1 on 15 August 2007	2	0	0
Longtom	0	0	2 on 13 December 2008	6
Non-identified perennial	1 on 12 October 2007	1	0	0
	1 on 19 December 2007	2		
Fall panicgrass	2 on 30 June 2007	2	0	0
	1 on 19 December 2007	3		
	1 on 17 February 2008	1		
Longspike beardgrass	0	0	1 on 24 May 2008	1
			2 on 28 June 2008	5
Browntop signalgrass	2 on 15 August 2007	2	0	0
Bushy bluestem	1 on 17 February 2008	1	1 on 13 December 2008	10
Dallisgrass	1 on 30 June 2007	1	0	0
Flatsedge	0	0	1 on 14 February 2009	1
Nealley's sprangletop	1 on 15 August 2007	2	0	0

^a Pupa was collected

saccharalis and proportions of recovered *D. saccharalis* per percent plant relative abundance (Fig. 6.5) were not detected between years ($F = 0.93$; $df = 1, 8.5$; $P = 0.361$ and $F = 0.48$; $df = 1, 8.0$; $P = 0.508$, respectively) and among dates ($F = 1.02$; $df = 6, 11.1$; $P = 0.459$ and $F = 0.67$; $df = 6, 6.4$; $P = 0.681$, respectively). In addition, for both johnsongrass and Vasey's grass, year \times date interactions were not significant ($P > 0.05$) for the proportions of recovered *D. saccharalis* and proportions of recovered *D. saccharalis* per percent plant relative abundance.

6.3.5. Spring Stem Borer Infestations in Rice Fields

In early April, old rice stubble was present in all sampled fallow fields but one, which had been grazed by cattle. When present, rice stubble had evidence of stem borer injury from the previous year, but did not host *E. loftini* immatures. However, one *D. saccharalis* pupa was recovered in April 2008 [i.e., 0.04 ± 0.04 immatures per m^2 (mean \pm SE)]. While dead rice stubble was the only rice material available in fallow fields during the first year of the study (April 2007), young rice plants grew in April 2008. Young rice tillers, present at a density of 37.7 ± 7.7 tillers per m^2 , measured 18.3 ± 1.1 cm (mean \pm SE) and harbored 0.7 ± 0.2 *E. loftini* immatures per m^2 (mean \pm SE). Among the 17 recovered *E. loftini* immatures, 64, 18, and 18% were small, medium, and large larvae, respectively. Weedy grasses were also collected in fallow rice fields. Canarygrass was present at densities of 1.5 ± 0.5 and 1.0 ± 0.5 tillers per m^2 (mean \pm SE) in April 2007 and 2008, respectively, with one recovered *E. loftini* larva in April 2007 (100% of the recovered immatures in fallow rice). Bristlegrass was present at densities of 0.1 ± 0.1 and 1.9 ± 0.9 tillers per m^2 (mean \pm SE) in April 2007 and 2008, respectively, with five recovered *E. loftini* larvae in April 2008 (23% of the recovered immatures in fallow rice fields).

During both years of the study, stem borer injury or infestations in young rice plants were not observed in early April and late May. By late June 2007, newly planted rice fields on each of the

three farms of the study were at panicle differentiation or boot stages. Stem borer injury, comprised of one bored tiller and one tiller with feeding signs in the leaf sheath [i.e., 0.04 ± 0.03 injured tillers per m^2 (mean \pm SE)], was recorded in the older rice field (boot stage) in June 2007. By late June 2008, young rice fields were at panicle differentiation, 70% boot and 30% heading, or 100% heading stages. Stem borer injury and infestations were observed in one field (70% boot and 30% heading), with an average of 1.67 ± 0.81 injured tillers per m^2 (mean \pm SE) and a total of three *D. saccharalis* larvae recovered from one quadrat [i.e., 0.11 ± 0.11 immatures per m^2 (mean \pm SE)].

6.3.6. Adult Stem Borer Trapping

Eoreuma loftini moth trap catches (Fig. 6.6) were 2-fold greater during the second year than during the first year of the study ($F = 7.68$; $\text{df} = 1, 7.9$; $P = 0.025$). Differences in trap catches among dates were also detected ($F = 5.60$; $\text{df} = 6, 56.9$; $P < 0.001$), with moth catches lowest during the winter and greatest in October (Fig. 6.6). However, there was some evidence ($P \leq 0.1$) for a year \times date interaction ($F = 1.97$; $\text{df} = 6, 56.9$; $P = 0.086$). For both years of the study, trap catches were comparable for fall and winter trapping. However, the greatest trap catches during the second year of the study were associated with greater catches between April and August with a peak in May, which was not observed during the first year of the study (Fig. 6.6). *Diatraea saccharalis* traps did not function during December and February samplings because the eclosion of virgin females used as lures did not occur. Thus, data on *D. saccharalis* flight activity during the winter were not collected. *Diatraea saccharalis* moth trap catches were variable but showed differences among dates ($F = 4.30$; $\text{df} = 4, 38.1$; $P = 0.006$), with an increase (8.4-fold) from April to October (Fig. 6.6). Differences in *D. saccharalis* moth trap catches between the two years of the study were not detected ($F = 1.80$; $\text{df} = 1, 4.3$; $P = 0.247$), and the year \times date interaction was not significant ($F = 1.26$; $\text{df} = 4, 38.1$; $P = 0.303$).

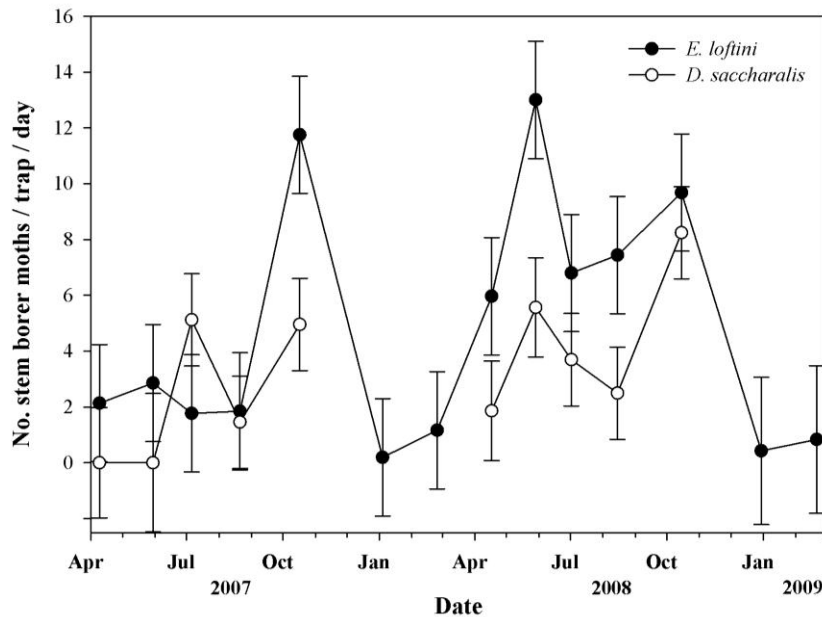


Fig. 6.6. *Eoreuma loftini* and *D. saccharalis* adult trap catches (LS means \pm SE) in habitats adjacent to rice fields in Texas, 2008-2009. Markers were not included on the figure when traps did not function

6.4. Discussion

6.4.1. *Eoreuma loftini* Infestations in Non-Crop Hosts

As early as in the 1920s (Van Zwalunwenburg 1926), it was recognized that many large-stemmed grasses could host *E. loftini*. However, *E. loftini* non-crop hosts have only recently received consideration for pest management (Beuzelin et al. 2010b, Showler et al. 2011). Our study provides the first quantification of seasonal *E. loftini* infestations in plants other than field crops. Under on-farm conditions of Texas Gulf Coast rice agroecosystems, infestations in non-crop grasses occurred early during the spring when young rice does not harbor *E. loftini*.

Eoreuma loftini infestations in non-crop grasses subsequently built up during the rice growing season, and were as high as 5.7 immatures per m² during the winter, suggesting that weedy habitats surrounding rice fields are major overwintering areas. April sampling in fallow rice fields that had not been cultivated showed that overwintering *E. loftini* larvae are not found in

rice stubble. However, grassy weeds and volunteer rice growing in fallowed fields can serve as host during the spring.

Pheromone trap data showed that, despite reduced numbers during the cold season, *E. loftini* moths fly year-round in or near non-crop habitats. This is consistent with adult seasonal patterns reported by Beuzelin et al. (2010b), and with observations of all developmental stages being present at any time of the year in sugarcane fields of the Texas Lower Rio Grande Valley (Meagher et al. 1994, van Leerdaam et al. 1986). Rodriguez-del-Bosque et al. (1995) also reported the continuous emergence of *E. loftini* adults during the winter and spring in northern Tamaulipas, Mexico. Thus, the relative role of various host plants in *E. loftini* population dynamics is a function of plant availability, attractiveness, and suitability throughout the year.

Assessment of the seasonal abundance and phenology of non-crop graminoids of Texas Gulf Coast rice agroecosystems as well as associated *E. loftini* infestations, assisted in identifying primary non-crops hosts and their potential role in the pest's population dynamics. Johnsongrass, Vasey's grass, ryegrass, brome, Angleton bluestem, and hairy crabgrass were effective *E. loftini* hosts that allowed larval feeding and life cycle completion. Other grasses and sedges might also be suitable hosts. Our study suggests that johnsongrass, which is abundant throughout the year, plays a substantial role in *E. loftini* population build-up during the rice growing season. The observed lack of live johnsongrass tissue during the winter, however, probably decreased host suitability and subsequently *E. loftini* survival during this season. In addition to low temperatures, desiccation is a primary abiotic stem borer mortality factor during the winter (Rodriguez-del-Bosque et al. 1995). Therefore, we contend that *E. loftini* larvae establishing in johnsongrass during the fall will complete their life cycle during the winter despite increased mortality. However, it is unlikely that dead johnsongrass supports the development of young

larvae from *E. loftini* moths emerging during the winter. For Vasey's grass, the high proportion of recovered *E. loftini* (62%) and proportion of recovered *E. loftini* per percent plant relative abundance (5-6%) in February indicate that this host becomes increasingly infested during the winter. Vasey's grass is less infested than johnsongrass at comparable phenological stages (Beuzelin et al. 2010b, Showler et al. 2011) but maintains numerous green vegetative tillers throughout the year. Thus, the substantial perennial availability of live plant tissue suitable for *E. loftini* development likely allows Vasey's grass to be a primary overwintering host. In areas with relatively less johnsongrass or Vasey's grass (e.g., transition between farm roads and field margins), a more diverse mixture of graminoids was observed. Ryegrass and brome are *E. loftini* hosts in the spring, also playing a role in population build-up early during the rice growing season, even if only for a short window of time. Our study also indicated that canarygrass may play a comparable role in *E. loftini* population dynamics. Other annual and perennial grasses (i.e., crabgrass, Angleton bluestem) probably play a minimal role in *E. loftini* population dynamics although they may have more substantial roles if abundant in localized areas.

The present study is the first to our knowledge to quantitatively describe graminoids in non-crop habitats (i.e., field margins, roadsides, ditches) surrounding rice fields in the Texas Upper Gulf Coast area. These habitats were more variable than adjacent rice fields because they were not under intensive management, and plant species composition was not intentionally controlled by the producers. However, the three study farms exhibited comparable non-crop habitat compositions, regardless of management (mowing, burning, herbicide applications, absence of management) or localized soil and weather variations. Based on our observations, non-crop habitats sampled in our study appear to be representative of those encountered throughout rice

areas of the Texas Gulf Coast. The generalization of our results to other Gulf Coast agroecosystems, however, will require additional sampling in Texas and Louisiana.

6.4.2. *Diatraea saccharalis* Infestations in Non-Crop Hosts

Complementing earlier studies (e.g., Jones and Bradley 1924, Bynum et al. 1938, Bessin and Reagan 1990), we provided the first year-round quantification of *D. saccharalis* infestations in non-crop habitats. *Diatraea saccharalis* was found mostly in johnsongrass and Vasey's grass, and infestations were low relative to *E. loftini* infestations. Low areawide *D. saccharalis* populations in the study areas might explain the predominance of *E. loftini*. *Diatraea saccharalis* might also rely less on non-crop hosts than *E. loftini*. Adult *D. saccharalis* trapping data from our study provide evidence of moth activity in the vicinity of non-crop sampling areas. In addition, *D. saccharalis* infestations in experimental rice plots located within 1.25 km of non-crop sampling transects in Jackson County represented >99% of stem borer infestations in July-August 2007 (Chapter 8). In the Louisiana sugarcane agroecosystem, Bynum et al. (1938) and Ali et al. (1986) concluded that johnsongrass only played a minor role in *D. saccharalis* population build-up and overwintering. These observations suggest that non-crop hosts might contribute less to *D. saccharalis* populations than to *E. loftini* populations. Nevertheless, oviposition preference and immature performance studies would assist in quantifying the relative role of non-crop hosts in *D. saccharalis* population dynamics.

6.4.3. Pest Management Implications

Although weeds in rice fields such as Amazon sprangletop can increase stem borer infestations (Tindall 2004, Beuzelin et al. 2010b), cultural management typically keeps weed populations low (Kendig et al. 2003), which is why exclusively non-crop habitats surrounding rice fields were the focus of our study. Research in several agroecosystems showed that alternate

hosts in non-crop habitats could contribute to increased pest populations. Examples of this relationship include increased consperse stink bug, *Euschistus conspersus* Uhler, infestations in California tomato fields (Pease and Zalom 2010) and the build-up of the pyralid *Mussidia nigrivenella* Ragoon in Benin (Sétamou et al. 2000). Populations of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and twospotted spider mite, *Tetranychus urticae* Koch, feed on weedy hosts prior to moving into nearby cotton fields (Fleischer and Gaylor 1987, Wilson 1995). Our study showed that non-crop grasses are sources of *E. loftini* populations. Thus, non-crop habitat management tactics including mowing, applications of herbicides or insecticides, or the modification of weed species composition (Landis et al. 2000) could help improve rice integrated pest management (IPM). However, the value of this approach remains to be demonstrated. Relationships between non-crop host abundance, stem borer population levels, and associated crop yield losses have not been quantified. In addition, non-crop habitats can be a source of biodiversity enhancing natural enemy abundance (Altieri and Letourneau 1982, Norris and Kogan 2005). Although the red imported fire ant (*Solenopsis invicta* Buren), spiders, and predaceous beetles suppress *D. saccharalis* injury to weedy Louisiana sugarcane (Ali and Reagan 1985, Showler and Reagan 1991), their interactions with stem borer populations in non-crop habitats have not been determined. *Eoreuma loftini* non-crop hosts might also represent refuges for parasitic wasps (Meagher et al. 1998) observed during sampling. Therefore, designing non-crop habitat management tactics for rice IPM will have to integrate weed contribution to both pest and natural enemy populations (Landis et al. 2000, Norris and Kogan 2005).

6.4.4. Concluding Remarks

Assuming that host-specific sympatric stem borer strains do not occur (Pashley and Martin 1987, Martel et al. 2003, Vialatte et al. 2005), our study showed that non-crop grasses have the

potential to increase *E. loftini* pest populations. Thus, the manipulation of *E. loftini* non-crop sources may help decrease infestations in crop fields and slow down the spread of this invasive species. Further research needs to be conducted to quantify the relative contribution of *E. loftini* oviposition preference, immature performance, movement, and natural enemy suppression to pest source-sink interactions in the agroecosystem. Subsequently, the efficacy and economic benefits of non-crop habitat management tactics, implemented at both field and regional scales, will have to be assessed. Because *E. loftini* non-crop hosts can sustain *D. saccharalis* populations, management tactics targeting non-crop habitats could also decrease *D. saccharalis* pest populations. Together with previous research (e.g., Reay-Jones et al. 2008, Beuzelin et al. 2010b), our study provides a foundation for a more comprehensive stem borer management strategy including crop and non-crop components of the agroecosystem.

CHAPTER 7: OVIPOSITION AND LARVAL DEVELOPMENT OF THE MEXICAN RICE BORER (LEPIDOPTERA: CRAMBIDAE) ON RICE AND NON-CROP GRASS HOSTS

7.1. Introduction

Eoreuma loftini (Dyar) (Lepidoptera: Crambidae) is a stem borer indigenous to Mexico that has become an invasive pest of graminaceous crops in the Gulf Coast regions of Texas and Louisiana (Hummel et al. 2010). In addition to sugarcane, *Saccharum* spp., and rice, *Oryza sativa* L., *E. loftini* infests a wide range of non-crop graminoids (Van Zwalunwenburg 1926, Beuzelin et al. 2010b, Chapter 6). Periodic sampling in southeast Texas rice production areas showed that non-crop grasses host *E. loftini*, with densities between 0.2 and 5.7 immatures per m² over a 2-yr period (Chapter 6). Primary hosts were the perennial johnsongrass [*Sorghum halepense* (L.) Pers.] and Vasey's grass (*Paspalum urvillei* Steud.), and the spring annual ryegrass (*Lolium* spp.) and brome (*Bromus* spp.) (Chapter 6). Because non-crop grasses increase host availability, they play a role in *E. loftini* population dynamics and may contribute to economically damaging populations in host crops. However, the extent to which non-crop hosts increase *E. loftini* populations remains poorly understood.

Herbivore host-specific preference, development, survival, and fecundity are key factors influencing the relative contribution of multiple host plants to herbivore populations. Meagher et al. (1996a) observed variations in *E. loftini* immature development time and pupal weight among sugarcane genotypes, while differences in oviposition were not detected. Among popular Louisiana and Texas sugarcane cultivars, Reay-Jones et al. (2003, 2005d) did not find differences in *E. loftini* larval survival. Subsequent studies involving sugarcane showed that cultivar HoCP 85-845 is 17 to 37% less preferred for oviposition than LCP 85-384 based on egg clusters per plant, eggs per egg clusters, and eggs per plant (Reay-Jones et al. 2007b). Both Reay-Jones et al. (2007b) and Showler and Castro (2010a) also showed that *E. loftini* prefers

drought stressed sugarcane plants for oviposition. Increased preference was associated with a greater abundance of oviposition substrate (folded dry leaf material) and increased levels of free amino acids (FAAs). Beuzelin et al. (2010b, Chapter 6) compared natural *E. loftini* infestations in non-crop hosts and Showler et al. (2011) studied oviposition and injury on five weedy grasses, including johnsongrass and Vasey's grass. Oviposition on a per plant basis showed that johnsongrass received more *E. loftini* eggs than Vasey's grass. Johnsongrass also exhibited more adult exit holes than Vasey's grass, indicating differences in *E. loftini* immature performance (Showler et al. 2011).

Previous studies show that *E. loftini* oviposition preference and immature performance are impacted by host plant species or genotype, stress level, and phenological stage (Meagher et al. 1996a, Reay-Jones et al. 2007b, Showler et al. 2011). To better understand the role of non-crop hosts in rice agroecosystems of the Gulf Coast, a study was conducted to determine *E. loftini* oviposition preference for and larval development duration on rice and four primary non-crop hosts.

7.2. Materials and Methods

7.2.1. Greenhouse Experiment

A greenhouse experiment was conducted at the Texas A&M AgriLife Research and Extension Center at Beaumont, TX during the summer of 2009. Rice (cultivar Cocodrie), two perennial grasses (johnsongrass, Vasey's grass), and two annual grasses (brome, ryegrass) were studied. Rice and johnsongrass seeds were obtained from the Louisiana State University Agricultural Center Rice Research Station (Rayne, LA) and Azlin Seed Service (Leland, MS), respectively. Other seeds were obtained from on-farm collections in Chambers and Jefferson Counties, TX during 2007 (brome, ryegrass) and 2008 (Vasey's grass). Thirteen plant by stage

combinations, hereafter referred to as host treatments, were studied. Rice and the perennials were evaluated at three phenological stages. The annuals were evaluated at two phenological stages. At the time of *E. loftini* oviposition assessment, young rice was between the late tillering and panicle differentiation stages, and the young non-crop grasses were in vegetative growth (Table 7.1). Intermediate rice was early in the panicle exertion stage while the oldest tillers of intermediate johnsongrass and Vasey's grass exhibited emerging inflorescences and mature seed heads, respectively. Intermediate brome and ryegrass were in a vegetative stage (Table 7.1). Older rice plants exhibited maturing panicles in the hard dough stage while older johnsongrass and Vasey's grass had mature seed heads.

Plantings were scheduled to obtain the different phenological stages simultaneously (Table 7.1), with the earliest planting initiated on 14 April 2009 for Vasey's grass. Planting occurred in 3.8-L pots filled with soil provided by the Louisiana State University Central Research Station greenhouse services (2:1:1 soil:sand:peat moss mixture). For each host treatment, 25 to 30 pots were planted. Final plant density was reduced to one plant per pot, with the exception of young annuals, which had two plants per pot. For rice, three seeds were planted directly in each pot, and 2-3 wk after seedling emergence, all but one plant were removed. For non-crop grasses, seeds were soaked in a gibberellic acid solution (300 ppm, N-LARGE[™], Stoller Enterprises, Inc., Houston, TX) for 24-36 h at 20°C, and then planted in plastic flats (30 cm × 60 cm × 5 cm). Seven to 14 d after emergence, four seedlings were transplanted into each pot. Three wk after transplant, all but one plant were removed.

All plants were fertilized at transplanting with 300 mg of urea and ≈ 250 mL of Miracle-Gro[®] Water Soluble All Purpose Plant Food (24-8-16 N-P-K) solution at 3.7 g per L per pot. The first plantings of rice, johnsongrass, and Vasey's grass were fertilized a second time on 16 June with

Table 7.1. Rice and non-crop grass plant characteristics (LS means) recorded during *E. loftini* oviposition preference and larval development assessment in a greenhouse experiment, Beaumont, Texas, 2009

Host treatment ^a	Oviposition assessment								Development assessment		
	Age ^b (wk)	Fresh weight ^c (g)	Dry weight ^c (g)	No. tillers	Sum of tiller heights (cm)	No. leaves	No. dry leaves ^d	No. dry leaves / green leaves	No. tillers	Sum of tiller heights (cm)	Tiller stem diameter (mm)
Rice											
Young	5	8.8 fg	1.6 cd	4.6 ef	243.2 e	20.8 fg	2.2 e	0.12 ef	5.5 de	317.3 e	3.7 b
Intermediate	9	58.5 c	17.4 b	8.5 bcd	604.9 bcd	50.5 cd	12.8 cd	0.34 cd	10.4 cd	656.7 cd	3.7 b
Older	13	45.1 d	17.0 b	6.8 de	468.3 d	47.4 cd	23.7 a	1.04 a	8.2 de	523.9 cde	4.0 b
Johnsongrass											
Young	6	19.9 e	3.1 cd	2.0 f	148.5 ef	12.1 g	0.3 e	0.03 f	2.2 e	265.4 e	5.1 a
Intermediate	10	66.1 c	20.2 b	4.3 ef	565.3 cd	38.1 def	10.8 cd	0.41 c	6.0 de	728.9 c	4.1 b
Older	14	78.9 b	29.0 a	5.2 def	648.3 bc	47.5 cd	22.5 a	0.95 a	5.8 de	704.1 c	3.8 b
Vasey's grass											
Young	7	19.2 e	3.5 c	6.8 de	271.3 e	26.3 efg	3.7 e	0.18 def	8.2 de	426.9 de	3.0 c
Intermediate	12	102.8 a	26.8 a	12.2 b	1043.9 a	69.8 b	16.2 bc	0.30 cde	19.4 b	1549.6 a	3.6 bc
Older	17	60.5 c	18.2 b	11.5 bc	903.0 a	61.7 bc	25.7 a	0.74 b	15.6 bc	1174.8 b	3.7 b
Brome											
Young	6	0.8 g	0.2 d	2.5 f	59.0 f	10.8 g	1.2 e	0.13 ef	9.5 cd	297.9 e	2.1 de
Intermediate	10	13.1 ef	4.1 c	7.2 de	270.2 e	40.6 de	10.2 d	0.33 cd	10.3 cd	312.2 e	2.3 d
Ryegrass											
Young	6	1.3 g	0.2 d	8.1 cde	134.0 ef	26.0 efg	0.8 e	0.04 f	33.8 a	1212.9 b	1.5 f
Intermediate	10	9.0 fg	1.4 cd	24.5 a	726.2 b	104.8 a	20.0 ab	0.24 cde	27.1 a	1038.9 b	1.6 ef
<i>F</i> ^e		251.43	242.64	53.06	95.10	49.17	61.76	60.66	40.60	52.31	71.13

LS means within a column with the same letter are not different, Tukey's HSD ($\alpha = 0.05$)

^a LS means reported on a per plant basis, except for young annuals (2 plants)

^b Plant age post-emergence. Larval development assessment was subsequent to plant dissection 5-6 wk after oviposition assessment

^c Estimated from five separate representative plants

^d $\geq 1/3$ leaf was dry

^e df = 12, 144; $P < 0.001$

300 mg of urea and ≈ 80 mL of Miracle-Gro[®] solution per pot. On 21 July, the first and second plantings of rice, johnsongrass, and Vasey's grass, as well as the first plantings of brome and ryegrass were fertilized with 300 mg of urea and ≈ 80 mL of Miracle-Gro[®] solution per pot. Plants were provided with ≈ 0.5 L of water every other day.

Thirteen 1.3 m (l) \times 1.3 m (w) \times 1.8 m (h) cages were constructed from white PVC pipes (2.13-cm outside diameter) and covered with white polyester 0.25 mm netting. Cages were arranged in two adjacent rows of 6 and 7 cages each, perpendicular to the cooling panel of the greenhouse. For each host treatment, one pot was placed into each cage at a random location 1 wk prior to oviposition assessment. The experiment was arranged as a randomized complete block design with cages as blocks.

Insects collected from a colony maintained at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center in Weslaco, TX were used. The *E. loftini* colony was established from larvae collected in commercial sugarcane fields near Weslaco, TX during the spring 2009. Insects were reared on artificial diet (Martinez et al. 1988) at 25°C, 65% RH, and a photoperiod of L14:D10. Pupae were separated by sex, and shipped overnight to the Texas A&M AgriLife Research and Extension Center at Beaumont, TX. Pupae were kept in the greenhouse, and upon adult eclosion (< 24 h), 10 females and 5-10 males were confined together in 0.473-L paper containers (Neptune Paper Products, Newark, NJ) for 24 h to allow for mating. Adults were released between 1700 and 1900 h from one paper container placed at the center of each cage. *Eoreuma loftini* releases occurred between 14 and 26 August. After allowing for three full nights of egg-laying, each plant was visually inspected for eggs. The number of oviposition events (i.e., egg clusters and single eggs laid ≥ 5 mm from one another) and eggs per oviposition event were determined using a magnifying lens. With the exception of two cages, where a small proportion

of the eggs were recovered on the mesh cloth, *E. loftini* oviposition exclusively occurred on plant material. Eggs laid on the mesh cloth were destroyed and not included in data analyses.

After oviposition data collection, plants were maintained in cages for 5-6 wk and then dissected for *E. loftini* larvae and pupae (18 September-4 October). Recovered pupae were kept in the greenhouse in 30-mL plastic cups until adult eclosion. Recovered larvae were reared on artificial diet (Martinez et al. 1988) in plastic cups maintained in the greenhouse until pupation and adult eclosion. Adult eclosion was recorded daily until the experiment was ended on 24 November.

Temperatures in the greenhouse were recorded every 15 min using two HOBO U10 data loggers (Onset Computer Corporation, Pocasset, MA). The cages closest and farthest from the greenhouse cooling panel each had one data logger located 1.2 m above the floor. Temperatures in each of the 13 cages were estimated using Eq. (7.1).

$$T_i = \frac{6-i}{6} \times T_0 + \frac{i}{6} \times T_6 \quad (7.1)$$

where:

T_i = the temperature in cage at i^{th} position, with $i \in \{0,1,2,3,4,5,6\}$ and $i = 0$ for the cage closest to the cooling panel; T_0 = the temperature recorded in the cage closest to the cooling panel; T_6 = the temperature recorded in the cage farthest from the cooling panel.

7.2.2. Plant Measurements

The numbers of tillers, numbers of green and dry leaves, and tiller heights from soil level to the tip of the tallest leaf were recorded for each plant in each cage immediately prior to moth release. From five representative plants not used for oviposition assessment, numbers of tillers, tiller heights, and plant fresh biomasses were recorded for each host treatment. Dry biomass was recorded after 5 d in an oven at 75°C. For each host treatment, simple linear regressions (Proc

REG, SAS Institute 2008) were conducted using the sum of tiller heights by plant as the explanatory variable, and plant fresh and dry biomasses as response variables. Parameters from these regressions were used to estimate biomasses for each plant in each cage. During plant dissection, numbers of tillers, tiller heights, and tiller diameters (as measured ≈ 1 cm below the 1st apparent node, or ≈ 3 cm above the cut if no node present) were recorded for each plant in each cage. One-way ANOVAs were used to compare plant characteristics as affected by the 13 host treatments and LS means were separated using the Tukey adjustment ($\alpha = 0.05$) (Proc MIXED, SAS Institute 2008). Cage was included in the ANOVA models as a random effect. In addition, multiple contrasts compared selected groups of host treatments (Proc MIXED, SAS Institute 2008) with p-values adjusted using the step-down Bonferroni method to control familywise error rates (Proc MULTTEST, SAS Institute 2008).

7.2.3. Oviposition Preference Estimation

Oviposition preference is a departure from random plant host selection when multiple plant hosts are simultaneously available for egg laying. A preference coefficient (Wilson and Gutierrez 1980, Murphy et al. 1991, Reay-Jones et al. 2007b) for a host plant, which accounts for plant availability, can be estimated using Eq. (7.2).

$$\hat{\alpha}_i = \frac{n_i/A_i}{\max(n/A)} \quad (7.2)$$

where:

$\hat{\alpha}_i$ = the estimated preference coefficient for the i^{th} host; n_i = the number of eggs laid on the i^{th} host; A_i = the availability of the i^{th} host (fresh biomass in g, dry biomass in g, sum of tiller heights in cm of tiller); $\max(n/A)$ = the maximum number of eggs laid on one host, adjusted for relative plant availability, across the different hosts. Oviposition on each available host plant can in turn be determined using Eq. (7.3).

$$\hat{n}_i = n_{total} \frac{\hat{\alpha}_i A_i}{\sum_{i=1}^I \hat{\alpha}_i A_i} \quad (7.3)$$

where:

\hat{n}_i = the estimated relative oviposition selection in total no. eggs or no. oviposition events for the i^{th} host; n_{total} = the total no. eggs or oviposition events laid across all hosts; $\hat{\alpha}_i$ = the estimated preference coefficient for the i^{th} host; A_i = the relative availability of the i^{th} host.

Relative oviposition preference coefficients as affected by host treatment, and accounting for plant availability in g of fresh biomass, g of dry biomass, or cm of tiller, were estimated with least square non-linear regressions (JMP, SAS Institute 2002) using Eq. (7.3). Differences in preference coefficients were determined using overlap of 95% confidence intervals [parameter estimate \pm SE $\times t_{(a/2, df_{error})}$ with $t_{(a/2, df_{error})} = 1.975$]. In addition, oviposition event size (no. eggs per oviposition event) was compared among host treatments using a one-way ANOVA that included cage and cage \times host treatment as random effects (Proc MIXED, SAS Institute 2008). Pearson correlations among preference coefficients and LS means of selected plant characteristics were determined using Proc CORR (SAS Institute 2008).

7.2.4. Larval Development Duration Estimation

Using estimates from van Leerdaam (1986), larval development duration in degree-days above a lower developmental threshold ($^{\circ}\text{D} > T_0$) was estimated for each larva or pupa recovered from a plant dissection that produced an adult. Van Leerdaam (1986) studied *E. loftini* immature development durations at temperatures between 20 and 32°C on both artificial diet and sugarcane stalk sections. Results derived from van Leerdaam (1986) suggest that egg and pupal development durations in $^{\circ}\text{D} > T_0$ are approximately constant regardless of food source (87.5 $^{\circ}\text{D} > 13.6^{\circ}\text{C}$ for eggs, and 124.9 $^{\circ}\text{D} > 14.0^{\circ}\text{C}$ and 121.6 $^{\circ}\text{D} > 13.8^{\circ}\text{C}$ for male and female pupae, respectively).

Duration to complete larval development on artificial diet is $349.3^{\circ}\text{D} > 14.9^{\circ}\text{C}$ and $378.1^{\circ}\text{D} > 14.6^{\circ}\text{C}$ for males and females, respectively (van Leerdam 1986).

For each recovered immature, the time of larval eclosion was estimated by summing $^{\circ}\text{D}$ from the day subsequent to moth release at 1200 h until the duration of the egg stage was attained. Time of pupation was estimated by summing $^{\circ}\text{D}$ from the day of adult eclosion at 1200 h backwards until the duration of the pupal stage was attained. When pupae were recovered during plant dissection, larval development occurred exclusively on the plant, and $^{\circ}\text{D}$ between larval eclosion and pupation were computed directly. When larvae were recovered, development occurred on the plant and subsequently on diet. Thus, total larval development duration on the plant was estimated using Eq. (7.4).

$$\hat{D}_{total_{ij}} = \frac{\sum_{ecl}^{dis} {}^{\circ}D_{ij}}{1 - \frac{\sum_{dis}^{pup} {}^{\circ}D_{ij}}{D_{total_{diet}}}} \quad (7.4)$$

where:

$\hat{D}_{total_{ij}}$ = the estimated total larval development duration on the i^{th} host for the j^{th} larva; $\sum_{ecl}^{dis} {}^{\circ}D_{ij}$ = the sum of $^{\circ}\text{D}$ from larval eclosion to plant dissection on the i^{th} host for the j^{th} larva; $\sum_{dis}^{pup} {}^{\circ}D_{ij}$ = the sum of $^{\circ}\text{D}$ on artificial diet from plant dissection to pupation for the j^{th} larva recovered from the i^{th} host; and $D_{total_{diet}}$ = the total larval development duration on artificial diet (van Leerdam 1986). This approach assumed that larval development on artificial diet after plant dissection was not affected by prior feeding on the host plant. Because substantial interplant movement of neonates occurred within each cage under our experimental conditions, all host treatments were infested with *E. loftini*, and the duration of larval development could be estimated for males and females on all 13 host treatments.

Larval development durations were compared using a two-way ANOVA with host treatment and sex as factors (SAS Proc MIXED, SAS Institute 2008). Because a relative larval development of 0.15 corresponds to late first or early second instars (van Leerdam 1986), larvae for which relative development on plant prior to dissection ($1 - \sum_{dis}^{pup} D_{ij} / D_{total_{diet}}$) was less than 0.15 were eliminated from the analysis. ANOVA random effects included cage and cage \times host treatment. When fixed effects were detected ($P < 0.05$), the Tukey adjustment ($\alpha = 0.05$) was used to separate LS means. In addition, multiple contrasts compared selected groups of host treatments (Proc MIXED, SAS Institute 2008) with p-values adjusted using the step-down Bonferroni method (Proc MULTTEST, SAS Institute 2008). Pearson correlations between LS means of development durations and preference coefficients, and LS means of selected plant characteristics, were determined using Proc CORR (SAS Institute 2008).

7.3. Results

7.3.1. Plant Characteristics

The 13 host treatments studied in this experiment presented a wide range of biomass, tiller, and leaf availability to moths and larvae (Table 7.1, Table 7.2). Five to 6 wk after oviposition, brome and ryegrass were still in vegetative growth but showed broken and desiccated injured tillers associated with larval feeding. For young rice, non-injured tillers were between milk and hard dough stages but injured tillers exhibited dead panicles in the boot or panicle exertion stages. Intermediate and older rice exhibited non-injured tillers with mature panicles and senescent foliage; however, tillers sustaining *E. loftini* boring injury during panicle exertion displayed whiteheads (blank panicles with dead grain). For perennial grasses, young johnsongrass and Vasey's grass exhibited maturing and mature seed heads, respectively. Intermediate and older johnsongrass showed young vegetative tillers growing from rhizomes in

Table 7.2. Contrasts comparing plant characteristics recorded during *E. loftini* oviposition preference and larval development assessment in a greenhouse experiment, Beaumont, Texas, 2009

Comparison ^a	Oviposition assessment							Development assessment		
	Fresh weight	Dry weight	No. tillers	Sum of tiller heights	No. leaves	No. dry leaves	No. dry leaves / green leaves	No. tillers	Sum of tiller heights	Tiller stem diameter
Non-crop grasses vs. rice	0.08	8.3*	11.99*	3.31	3.03	4.79	34.55*	36.67*	51.47*	72.54*
Perennials vs. rice	186.15*	99.56*	0.50	49.15*	1.36	0.17	4.63	2.19	57.62*	0.97
Annuals vs. rice	382.19*	402.59*	42.00*	33.82*	4.55	27.91*	93.62*	120.89*	24.17*	388.78*
Perennials vs. annuals	1449.89*	1202.08*	47.54*	212.04*	1.55	44.87*	82.64*	129.71*	6.24*	595.71*
Brome vs. rice	252.18*	246.48*	5.92*	88.97*	16.74*	43.08*	48.38*	2.06	13.67*	183.21*
Johnsongrass vs. rice	100.87*	95.81*	18.13*	0.34	5.43	2.81	1.10	8.09*	2.02	26.15*
Ryegrass vs. rice	283.34*	319.51*	176.28*	0.09	58.66*	5.18	85.29*	287.67*	142.20*	378.62*
Vasey's grass vs. rice	184.64*	56.16*	30.03*	133.6*	18.77*	5.69	7.17*	29.22*	137.50*	11.63*
Johnsongrass vs. Vasey's grass	12.57*	5.26*	94.84*	120.43*	44.13*	16.50*	2.65	68.05*	106.18*	72.68*
Johnsongrass vs. brome	618.17*	598.03*	1.89	99.11*	4.13	25.64*	36.19*	15.84*	24.69*	327.96*
Johnsongrass vs. ryegrass	666.45*	709.15*	291.92*	0.68	94.59*	0.60	68.81*	380.43*	113.49*	577.55*
Vasey's grass vs. brome	785.90*	501.87*	53.80*	390.88*	63.47*	75.63*	20.80*	11.55*	201.24*	109.93*
Vasey's grass vs. ryegrass	840.21*	604.06*	70.15*	113.16*	14.32*	19.45*	46.79*	147.04*	2.06	269.20*
Brome vs. ryegrass	0.76	3.94*	205.68*	69.51*	115.07*	15.32*	4.33	200.83*	203.38*	29.23*

* Indicates $P < 0.05$ using the step-down Bonferroni adjustment for multiple contrasts

^a df = 1, 144

addition to flowering and mature tillers with dispersed seeds. Intermediate and older Vasey's grass displayed a mixture of vegetative, flowering, mature, and senescing tillers.

7.3.2. *Eoreuma loftini* Oviposition

A total of 5,965 *E. loftini* eggs were recorded during this study. The majority of eggs (99.5%) were laid in clusters, with 283 clusters recorded. Thirty-one single eggs were also observed. Hereafter, single eggs and egg clusters are referred to as oviposition events. Ninety-six point five percent of the oviposition events and 99.2% of the eggs were laid in folds on dry plant material, leaf or leaf sheath. The size of *E. loftini* oviposition events averaged 19.0 ± 1.0 (SE) eggs, and showed limited differences ($F = 2.00$; $df = 8, 46$; $P = 0.068$) among the 13 host treatments (Fig. 7.1).

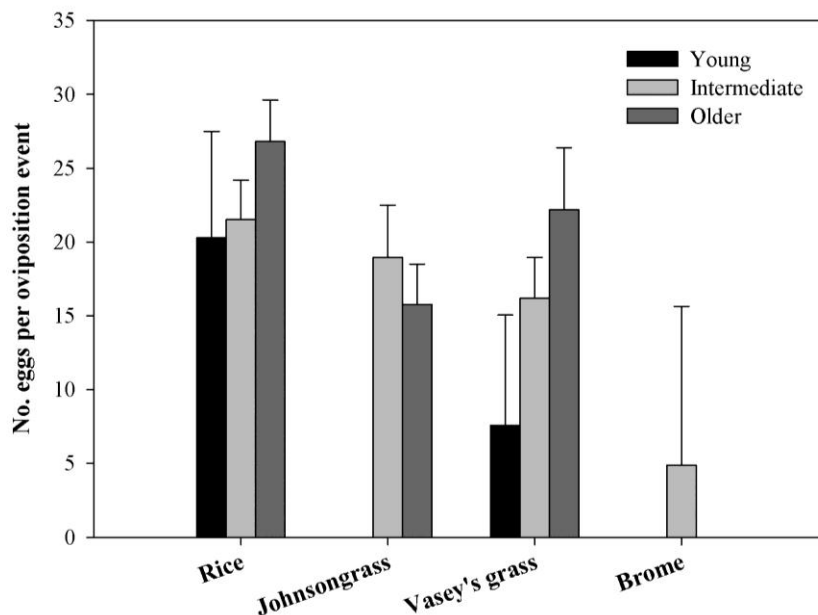


Fig. 7.1. Size of *E. loftini* oviposition events (LS means) on rice and four non-crop hosts. Bars with the same letter are not different, Tukey's HSD ($\alpha = 0.05$). Error bars are one SE in length

Preference coefficients for number of eggs or oviposition events per g plant fresh biomass, per g plant dry biomass, and per cm of tiller accounted for about 60% of variability in the observed oviposition data ($P < 0.05$, Fig. 7.2). Regardless of plant measure of availability, rice

was more preferred than non-crop grasses with either young, or intermediate, or older rice having preference coefficients equal to 1 (Fig. 7.2). Young brome, young johnsongrass, and young and intermediate ryegrass were assigned preference coefficients equal to zero because oviposition did not occur on these hosts (Fig. 7.2).

Based on the number of eggs per g of plant fresh biomass, older rice was the most preferred host (Fig. 7.2), followed by intermediate rice (24% less preferred), and intermediate and older perennials (63 to 76% less preferred). Preference for intermediate brome was 94% lower than that for older rice, but was not different from that for other hosts. The variability of preference for young rice and Vasey's grass was high as shown by large standard errors (Fig. 7.2). Thus, although preferences were low for these young hosts, differences with preferences for intermediate and older hosts were not detected. Based on the number of eggs per g of plant dry biomass, young rice was the most preferred host (Fig. 7.2). However, preferences based on plant dry biomass were associated with larger standard errors than those based on plant fresh biomass and sum of tiller heights (Fig. 7.2). Therefore, large 95% confidence intervals did not detect differences among the 13 preference coefficients. Based on the number of eggs per cm of tiller, older rice was the most preferred host (Fig. 7.2). The pattern for preference based on the number of eggs per cm of tiller was comparable to that of preference based on the number of eggs per g of plant fresh biomass. However, when the sum of tiller heights was used as measure of plant availability, differences were greater between preferences for young and intermediate rice (0.55 vs. 0.22), and between preferences for young and older rice (0.79 vs. 0.46).

Preference based on the number of oviposition events per g of plant fresh biomass and on the number of oviposition events per cm of tiller showed that intermediate rice was the most preferred host (Fig. 7.2). Preferences based on fresh biomass and cm of tiller were less for

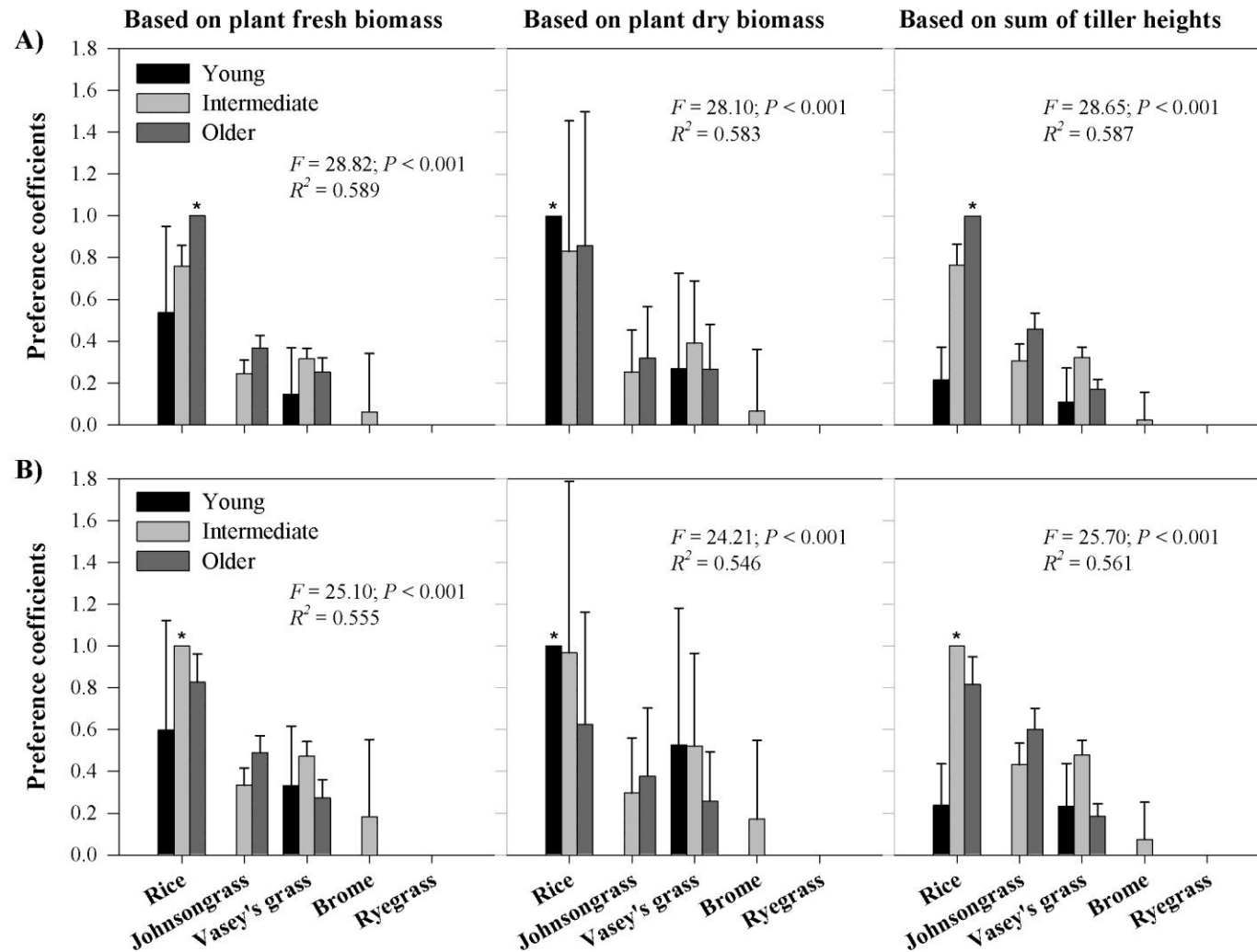


Fig. 7.2. Oviposition preference coefficients predicting *E. loftini* (A) eggs and (B) oviposition events based on fresh weight, dry weight, or sum of tiller heights as measures of plant availability. Coefficients estimated using non-linear least square regressions range from 0 (no oviposition) to 1 (maximum preference, marked with * on the figure). Error bars are one SE in length

the most preferred stage of johnsongrass (51 and 40%, respectively) and Vasey's grass (53 and 52%, respectively). Based on the number of oviposition events per g of plant dry biomass, young rice was the most preferred host. Preference for the most preferred stage of johnsongrass (older) and Vasey's grass (young) were 62 and 47% less, respectively (Fig. 7.2). Correlations among preference coefficients predicting numbers of eggs ($r = 0.767$ to 0.951) and among those predicting numbers of oviposition events ($r = 0.732$ to 0.937) were detected ($P < 0.05$). In addition, correlations ($P < 0.05$) between preference coefficients predicting numbers of eggs and those predicting numbers of oviposition events ranged between 0.666 and 0.949 .

Preference coefficients were not correlated ($P > 0.05$) with the number of dry leaves per plant and stem diameter (Table 7.3). However, preference coefficients predicting numbers of eggs and oviposition events based on fresh biomass and sum of tiller heights were positively correlated with the number of dry leaves per green leaves (Table 7.3). Preference coefficients based on dry biomass were not associated (Table 7.3) with the number of dry leaves per green leaves.

7.3.3. Larval Development Duration

Estimated *E. loftini* larval development duration changed with host treatment ($F = 10.45$; $df = 12, 90$; $P < 0.001$; Fig. 7.3) but differences between male and female larvae were not detected ($F = 1.02$; $df = 1, 410$; $P = 0.312$). In addition, the host treatment \times sex interaction was not significant ($F = 0.55$; $df = 12, 410$; $P = 0.883$). Development duration on johnsongrass was not different from that on Vasey's grass (Table 7.4), and on brome it was not different from that on ryegrass (Table 7.4). Larval development was 1.4-fold longer on non-crop grasses than on rice (Fig. 7.3). However, while development was 1.7-fold longer on the perennials than on rice, differences in development durations between annuals and rice were not detected ($P > 0.05$;

Table 7.3. Pearson correlations ($n = 13$) of oviposition preference coefficients with larval development durations and selected plant characteristics

	Larval development duration		No. dry leaves		No. dry leaves per green leaves		Tiller stem diameter	
	r	P	r	P	r	P	r	P
Preference coefficient								
Eggs per g fresh weight	-0.320	0.287	0.438	0.135	0.604	0.029	0.461	0.113
Eggs per g dry weight	-0.266	0.379	0.220	0.470	0.355	0.234	0.436	0.137
Eggs per g cm of tiller	-0.269	0.374	0.528	0.064	0.694	0.009	0.452	0.121
Oviposition events per g fresh weight	-0.234	0.441	0.381	0.199	0.505	0.079	0.459	0.115
Oviposition events per g dry weight	-0.173	0.572	0.128	0.678	0.221	0.467	0.403	0.173
Oviposition events per g cm of tiller	-0.156	0.612	0.482	0.095	0.601	0.030	0.462	0.112
Larval development duration	1	-	0.015	0.962	0.033	0.914	0.556	0.048

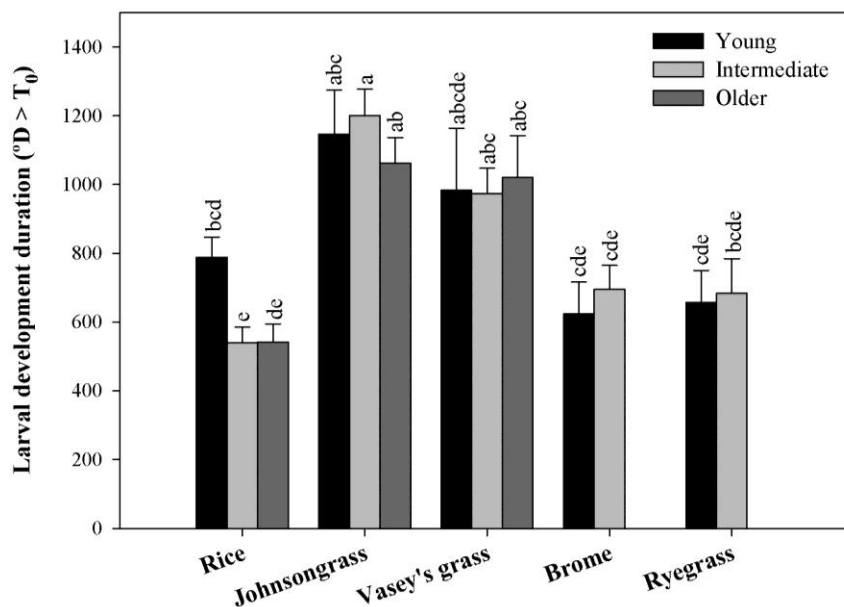


Fig. 7.3. *E. loftini* larval development durations (LS means) in degree-days above a minimum temperature threshold ($^{\circ}\text{D} > T_0$). Bars with the same letter are not different, Tukey's HSD ($\alpha = 0.05$). Error bars are one SE in length

Table 7.4). Development durations were not affected by plant stage, except for rice on which larvae developed 1.5-fold slower on young plants than on the intermediate and older ones (Fig. 7.3). Correlations between larval development durations and oviposition preference coefficients were not detected ($0.287 \leq P \leq 0.611$). Except for a positive association ($P < 0.05$) with stem diameter (Table 7.3), larval development duration was not correlated with plant availability estimates (Table 7.1).

Table 7.4. Contrasts comparing *E. loftini* larval development durations on rice and four non-crop hosts in a greenhouse experiment, Beaumont, Texas, 2009

Comparison	Larval development duration ^a
Non-crop grasses vs. rice	40.48*
Perennials vs. rice	63.70*
Annuals vs. rice	0.61
Perennials vs. annuals	38.35*
Brome vs. rice	0.31
Johnsongrass vs. rice	68.05*
Ryegrass vs. rice	0.40
Vasey's grass vs. rice	20.58*
Johnsongrass vs. Vasey's grass	2.38
Johnsongrass vs. brome	36.22*
Johnsongrass vs. ryegrass	28.52*
Vasey's grass vs. brome	12.28*
Vasey's grass vs. ryegrass	10.04*
Brome vs. ryegrass	0.02

* Indicates $P < 0.05$ using the step-down Bonferroni adjustment for multiple contrasts

^a df = 1, 90

7.4. Discussion

Eoreuma loftini oviposition preference for rice was greater than that for four primary non-crop hosts occurring in Gulf Coast rice agroecosystems, based on plant fresh biomass, dry biomass, and sum of tiller heights. Reay-Jones et al. (2007b) found rice more attractive for oviposition than sugarcane based on plant dry biomass. Among non-crop hosts, Showler et al.

(2011) observed that *E. loftini* oviposited a greater proportion of eggs on johnsongrass than on Vasey's grass. In our study, *E. loftini* showed comparable oviposition preferences for these two perennial grasses. Our data also suggest that under choice conditions, *E. loftini* moths will lay a limited number of eggs on brome and ryegrass.

Eoreuma loftini eggs were laid almost exclusively in folds on dry plant material regardless of plant host. In addition, oviposition preference coefficients based on fresh plant biomass and sum of tiller heights were positively correlated with the ratio of dry leaves to green leaves. These observations confirm that *E. loftini* oviposition preference is associated with the availability of folds in dry leaf material (Showler and Castro 2010b), which may explain why young plants were not preferred. However, Showler and Castro (2010b) showed that variations in oviposition were also associated with the presence of live plant material. Both Showler and Castro (2010a) and Reay-Jones et al. (2007b) associated increases in selected free amino acid (FAA) concentrations with increased *E. loftini* oviposition preference. Potential differences in foliar FAA concentrations may also help explain differences in preference. Additional morphological and biochemical factors likely affect *E. loftini* oviposition preference. For example, greater sugarcane leaf pubescence is associated with decreases in oviposition preference exhibited by females of the sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) (Sosa 1990). For *Chilo partellus* Swinhoe (Lepidoptera: Crambidae), variations in green leaf volatiles emitted by various grass hosts are potentially associated with differences in oviposition preference (Birkett et al. 2006, Midega et al. 2011). Further studies addressing physical and chemical characteristics potentially affecting *E. loftini* oviposition preference will assist in better understanding the pest's biology and help identify host plant resistance traits.

Eoreuma loftini larvae infesting rice, brome, and ryegrass develop faster than those infesting johnsongrass and Vasey's grass. Van Leerdam (1986) estimated that larvae feeding on sugarcane (cultivar NCo 310) stalk sections in the laboratory completed development in 519°D > 14.6°C for females and 392°D > 14.9°C for males. In our study, the fastest larval development was 540°D, which occurred when neonates infested rice at the panicle exertion stage. Thus, *E. loftini* larval development may be shorter on sugarcane than on rice and the four non-crop hosts of our study. Although van Leerdam (1986) found that female larval development was slower than that of males, such differences were not detected in our study.

Using diet incorporation assays, Meagher et al. (1996a) reported variations in *E. loftini* immature development duration and pupal weight (i.e., fecundity) as affected by sugarcane genotype. The fecundity of *D. saccharalis* females reared on johnsongrass is reduced compared to that of females reared on corn (*Zea mays* L.) and sugarcane (Bessin and Reagan 1990). However, host plant physical and chemical factors in these studies were not identified. Physical constraints associated with stem diameter may impact *E. loftini* immature performance, because larger stems are more suitable for development (Showler et al. 2011). Nevertheless, the large-stemmed perennials in our study were less suitable as *E. loftini* hosts than rice and annuals that had relatively narrower stems. In addition, *E. loftini* larvae were observed feeding within stems but also extensively through stem walls of seemingly softer and more succulent grasses (rice, brome, ryegrass). These observations suggest that stem hardness is a key factor in determining *E. loftini* immature performance. Martin et al. (1975) and Keeping and Rutherford (2004) showed that sugarcane internode rind hardness is a source of larval antibiosis for the stem borers *D. saccharalis* and *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Stem fiber and relative lignin contents may also affect larval feeding and development (Rutherford et al. 1993).

Host plant nutritional quality is another key factor in determining *E. loftini* immature performance. Increased FAA concentrations have been consistently associated with enhanced nutritional quality of herbivore host plants (Showler 2001, Reay-Jones et al. 2007b, Showler and Castro 2010a). Therefore, differences in foliar and stem concentrations of FAAs may assist in understanding the impact of host plants on *E. loftini* larval development. Studies utilizing varying nitrogen fertilization levels to change host plant nutritional quality demonstrated impacts on herbivore immature performance. Nitrogen fertilization of cotton (*Gossypium hirsutum* L.) increased total plant N content, increased adult oviposition and larval feeding preference, and shortened immature development duration in *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) (Chen et al. 2008). For *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) feeding on corn, nitrogen fertilization increased plant stem and leaf N concentrations, increased larval survival and pupal weight, and was associated with numerical trends for faster immature development (Sétamou et al. 1993). *Eldana saccharina* females do not preferentially lay eggs on fertilized or water-stressed sugarcane when unfertilized or well-watered plants are also available for oviposition (Atkinson and Nuss 1989). However, the combination of nitrogen fertilization with water stress, which increases plant total N and FAA concentrations, results in greater survival, weight, and shorter development duration for larvae (Atkinson and Nuss 1989). Although exact mechanisms enhancing immature performance for *S. exigua*, *S. calamistis*, and *E. saccharina* are undetermined, changes in plant FAA and nitrogen content, nitrogen to carbohydrate ratio, and potential decreases in defensive compounds are likely involved (Atkinson and Nuss 1989, Sétamou et al. 1993, Chen et al. 2008). Similarly to these three lepidopteran pests, exact causes for differences in *E. loftini* immature performance as affected by host plant species and phenology have not been determined. Thus, in addition to FAAs, we

recognize that host plant-specific carbohydrate composition (A. T. Showler pers. com.), nitrogen to carbohydrate ratio, and allelochemicals impact nutritional quality. For example, johnsongrass produces dhurrin (Nicollier et al. 1983), a cyanogenic glucoside associated with decreased herbivory (Woodhead and Bernays 1978).

For crambid and pyralid stem borers of graminaceous crops, the relationship between oviposition preference and immature performance on crop, forage, and weedy grasses seems species-specific. In our study, *E. loftini* moths preferred laying eggs on rice, which was also the most suitable host, allowing relatively shorter larval development. However, brome and ryegrass, which seemed more suitable as *E. loftini* hosts than johnsongrass and Vasey's grass, were the least preferred hosts. Showler et al. (2011) showed that increased *E. loftini* oviposition preference for corn, compared with sorghum [*Sorghum bicolor* (L.) Moench] and sugarcane, was associated with increased performance, as measured by the number of adult exit holes. In the same study, oviposition preference and immature performance were greater on johnsongrass than Vasey's grass. The pyralid *E. saccharina* shows oviposition preference for four wild grasses and a sedge (Cyperaceae) as compared to corn (Atachi et al. 2005, Conlong et al. 2007). However, *E. saccharina* performance is inversely associated with preference on these hosts, with longer immature development, lower survival, and lower pupal weight observed on wild grasses than on corn (Shanower et al. 1993, Atachi et al. 2005). For *C. partellus*, positive associations between oviposition preference and immature performance were not detected. In choice assays, *C. partellus* consistently prefers *Pennisetum purpureum* Schumach., a forage grass, for oviposition (Ofomata et al. 2000, van den Berg et al. 2001, Midega et al. 2011). However, immature survival is extremely low on this grass (Ofomata et al. 2000, van den Berg et al. 2001).

Four non-mutually exclusive hypotheses could explain the evolution of the relationship between herbivore preference and performance (Thompson 1988). The time, patch dynamics, parasite/grazer, and enemy-free hypotheses respectively predict that the time a herbivore is exposed to a new host, the relative abundance of hosts, the herbivore feeding habits, and the suppression from natural enemies as affected by host shape the selection pressure causing the observed preference and performance relationship (Thompson 1988). Presumably native to northwest Mexico, *E. loftini* expanded its range into eastern Mexico before it was introduced into south Texas, from where it spread along > 600 km of Gulf Coast within 30 yr (Reay-Jones et al. 2007c). During this range expansion, *E. loftini* has likely been exposed to substantial changes in relative abundance of graminaceous crops, non-crop graminoids, and natural enemies. *Eoreuma loftini* preference and performance in our study are the results of changing selection pressures and could not have been predicted. In addition, preference and performance may vary within and among populations (Thompson and Pellmyr 1991, Assefa et al. 2009). Thus, the study of both preference and performance along with governing morphological and biochemical factors will continue to be needed to identify sources and sinks of *E. loftini* populations in agroecosystems.

Beuzelin et al. (Chapter 6) studied on-farm *E. loftini* immature infestations in non-crop grasses of Texas rice Gulf Coast agroecosystems but did not determine the role of underlying biological mechanisms. Our study provided insights on aspects of oviposition preference and immature performance, which impact egg partitioning among primary hosts and the length of larval development on these hosts. Host selection can be predicted based on oviposition preference and host availability using Eq. (7.3) (Wilson and Gutierrez 1980, Murphy et al. 1991, Reay-Jones et al. 2007b). Similarly, larval development duration can be used to predict *E. loftini* dynamics on primary hosts. However, host-specific survival and fecundity, which are key

performance parameters impacting population dynamics, were not determined in our study. In addition, potential *E. loftini* larval movement and preference, which may substantially impact larval mortality and infestations when hosts occur in mixture (Chapter 6), have not been documented. Combining results from our study and future research will help quantify the relative contribution of multiple host plants to *E. lotini* populations in rice agroecosystems.

CHAPTER 8: IMPACT OF RICE HARVEST CUTTING HEIGHT AND RATOON CROP ON LATE SEASON AND OVERWINTERING STEM BORER (LEPIDOPTERA: CRAMBIDAE) INFESTATIONS

8.1. Introduction

Lepidopteran and dipteran stem borers are major insect pests of rice, *Oryza sativa* L., in all production areas of the world (Pathak and Khan 1994). In the Upper Gulf Coast region of Texas, the stem borers *Diatraea saccharalis* (F.) and *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae) frequently infest rice, causing yield losses as severe as 2,000 kg/ha or 33% (Reay-Jones et al. 2007a). In addition, a third crambid, *Chilo plejadellus* Zincken, can cause sporadic damage (Bowling 1975, Hummel et al. 2009). While *D. saccharalis* and *C. plejadellus* have historically been pests in Texas rice (Bowling 1975), the invasive *E. loftini* has become a substantial problem since its first detection in south Texas during the 1980s (Browning et al. 1989, Reay-Jones et al. 2007c). Stem borer larval tunneling within rice culms may kill young tillers, resulting in deadhearts (dead vegetative tillers). When injury occurs later, the culm usually survives before heading, but injury to the vascular tissue results in a whitehead (dead panicle with unfilled grain). When injury occurs during ripening, the maturation of panicles suffers from a lack of uniformity in grain development and increased grain mortality. Mature panicles may also be lost because larval injury to the topmost node causing the culm to break (Bowling 1975, Browning et al. 1989, Way 2003).

Diatraea saccharalis and *E. loftini* pest pressure in Texas rice has increased in the past decade (Way et al. 2006, Reay-Jones et al. 2007a). In the neighboring state of Louisiana, *D. saccharalis* has become an increasing source of damage (Castro et al. 2004) and *E. loftini* was detected in rice areas for the first time in 2008 (Hummel et al. 2010). To manage stem borers, producers rely mainly on insecticides. However, economic thresholds have not been established although studies have helped to better time insecticide applications (Reay-Jones et al. 2007a),

and have provided results estimating yield loss as a function of *D. saccharalis* injury (Lv et al. 2008). Resistance screenings in Texas also compared relative stem borer injury levels and yield losses in experimental and commercial rice genotypes (Way et al. 2006). Because genotypes exhibited various resistance levels, cultivar resistance is expected to play an increasing role in stem borer integrated pest management (IPM) (Way et al. 2006, Reay-Jones et al. 2007b). Conversely, biological control research determined that the use of *Cotesia flavipes* (Cameron), a parasitoid of *D. saccharalis*, would not be a profitable IPM tactic (Lv et al. 2011). Studies in the Texas Gulf Coast rice agroecosystem showed that non-crop grasses adjacent to fields have the potential to increase *E. loftini* pest populations (Chapter 6). Thus, the manipulation of *E. loftini* non-crop hosts may also help decrease infestations in rice fields.

In the Upper Gulf Coast region of Texas and in southwest Louisiana, rice is typically planted in March-April (Blanche et al. 2009, Dou and Tarpley 2010) and harvested in July-August. In these areas, the length of the growing season allows for the production of a ratoon crop, which is a second crop developing from the main crop stubble (Bollich and Turner 1988, Harrell et al. 2009). The ratoon crop is generally harvested in October-November. Rice is traditionally harvested with the cutter bar set ≈ 40 cm above ground level. However, reducing main crop cutting height has the potential to increase ratoon yields (Harrell et al. 2009, McCauley et al. 2010). Thus, some farmers harvest ≈ 20 cm above ground level whereas some harvest at the traditional cutting height, but subsequently mow the stubble using a flail-shredder. Because shorter harvest cutting heights leave a smaller portion of rice culms intact, reducing harvest cutting height may impact stem borer infestations and subsequent areawide populations (Litsinger 1994).

Diatraea saccharalis and *E. loftini* adult trap catches in the Texas rice agroecosystem have shown that stem borer populations are high when ratoon rice is grown (Beuzelin et al. 2010b, Chapter 6). The production of a ratoon crop when high stem borer populations actively fly may therefore influence stem borer infestations and population dynamics. After harvest, main or ratoon crop stubble is often left intact in the field over the winter. Management practices such as pasturing, fall plowing, or winter flooding of stubble may help reduce overwintering stem borer populations (Litsinger 1994, Way and Espino 2010). However, the role of rice stubble as an overwintering habitat for *D. saccharalis* and *E. loftini* remains poorly studied. The objectives of the research reported in this chapter were to determine the effects of reducing rice main crop harvest cutting height and ratoon crop production on late season and overwintering *D. saccharalis* and *E. loftini* infestations.

8.2. Material and Methods

8.2.1. Experimental Field Plots

Two field experiments were initiated in 2007 and 2008 at the Texas A&M AgriLife Research Station (N 29.025°, W 96.441°) near Ganado, Jackson County, TX. Each year, six adjacent strips of land contained four nine-row plots (4.88 m × 1.71 m). A levee or a 1.33-m wide buffer rice plot separated strips while plots within strips were separated by a 2.44-m gap. In 2008, two of six strips contained four additional nine-row plots, each used exclusively for ratoon crop yield determination. Plots were drill planted with the rice cultivar Cocodrie at a rate of 89.6 kg seed/ha on 16 April 2007 and 8 April 2008. Standard fertilization, water management, and weed control were adopted according to the Texas Rice Production Guidelines (Texas A&M AgriLife 2008). One d prior to permanent flood, on 6 June 2007 and 21 May 2008, plots were treated with

lambda-cyhalothrin [34 g (AI)/ha] using a hand-held boom spray rig to control rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, infestations. Plots were not treated to manage stem borers.

8.2.2. Pre-Main Crop Harvest Data Collection

Three and 4 wk prior to main crop harvest in 2007 and 2008, respectively, between the milk and hard dough stages, each plot was separated into three 1.63-m sections (i.e., front, middle, and rear section). One randomly selected inner row was cut at soil level with a sickle to facilitate access to all remaining standing rows. The number of injured tillers (showing stem borer feeding signs larger than $\approx 2 \text{ cm}^2$) and whiteheads on the rows that were left intact were recorded by section, except for border rows that served as buffers. For the cut row, injured tillers and whiteheads were also recorded, and one section was randomly selected for destructive sampling. Rice from this section was placed in 50-L plastic bags, stored at the Texas A&M AgriLife Research and Extension Center at Beaumont, TX in a cold room at 13°C, and processed within 1 wk. Injured tillers were dissected to recover *D. saccharalis* and *E. loftini* immatures. The size of larvae was visually determined, with small, medium, and large larvae corresponding approximately to first-second, third, and fourth-fifth instars, respectively. In addition, stem borer location relative to the base of the culm was recorded as “low” (< 20 cm), “high” (> 20 cm and > 10 cm from the panicle base), or “near panicle” (< 10 cm from the panicle base).

8.2.3. Post-Main Crop Harvest Data Collection

The main crop was harvested using a small plot combine on 17 August 2007 and 26 August 2008. In each strip, two randomly selected plots were harvested with the cutter bar set 40 cm above soil surface, and the two remaining plots were harvested lower (20 cm). In 2008, additional plots grown for ratoon yield determinations were harvested either at 40 cm or 20 cm. Within 5 d following main harvest, rice stubble from one row in each plot was dug out by section

and collected for destructive sampling. Samples were placed in plastic bags, stored in a cold room at 13°C, and processed within 3 wk. All tillers were dissected to recover stem borers, whose larval size was determined and location within culms recorded as “near root crown” (within 4 cm of the root crown), “low” (between 4 cm and 20 cm), or “high” (> 20 cm).

8.2.4. Late and Post-Growing Season Data Collection

Subsequent to main crop harvest, rice managed to produce only a main crop was compared to rice managed to produce a main and ratoon crop (Fig. 8.1). Within 7 d of main crop harvest, on 24 August 2007 and 28 August 2008, three randomly selected strips were fertilized and re-flooded to produce a ratoon crop (Texas A&M AgriLife 2008). In 2007, the three remaining unmanaged strips were inadvertently destroyed during routine farming operations. Thus, two unmanaged replacement strips were used for assessment of main crop only rice. These replacement strips, which were directly adjacent to ratoon strips, each contained three plots. These plots were previously used for cultivar yield evaluation studies, and plot size, cultivar, and cultural practices were the same as those for plots in the original experimental design. However, main crop harvest cutting height was 26.4 ± 2.0 (SE) cm above soil surface. In 2008, plots in two of the six original strips were left unmanaged for assessment of main crop only rice.

In 2007 and 2008, 13-15 d prior to ratoon crop harvest, all plants from a randomly selected row in each plot were dug out by section. Samples were bagged and stored at 13°C until processed within 3 wk. All plant material was dissected to recover stem borers, whose larval size was recorded. In 2007, stem borer location within culms was recorded in the same manner as during post-main harvest data collection. Ratoon rice plots were harvested with a small plot combine (cutter bar 15 cm from soil surface) on 8 November 2007 and 3 November 2008. Grain yields adjusted to 12% moisture were determined from intact rows.

For the experiment initiated in 2007, on 18 January 2008 and 20 March 2008, all plant material from one row was collected by section in each plot. For the experiment initiated in 2008, samples were collected on 17 January 2009 and 28 March 2009. On each date, samples were bagged and stored at 13°C until being processed within 1 wk. All plant material was dissected to recover overwintering stem borers, whose larval size was recorded. Rice plant material remaining in the plots after main and ratoon crop harvest, hereafter referred to as main crop stubble and ratoon crop stubble, respectively, was comprised of stubble and regrowth from stubble (Fig. 8.1).

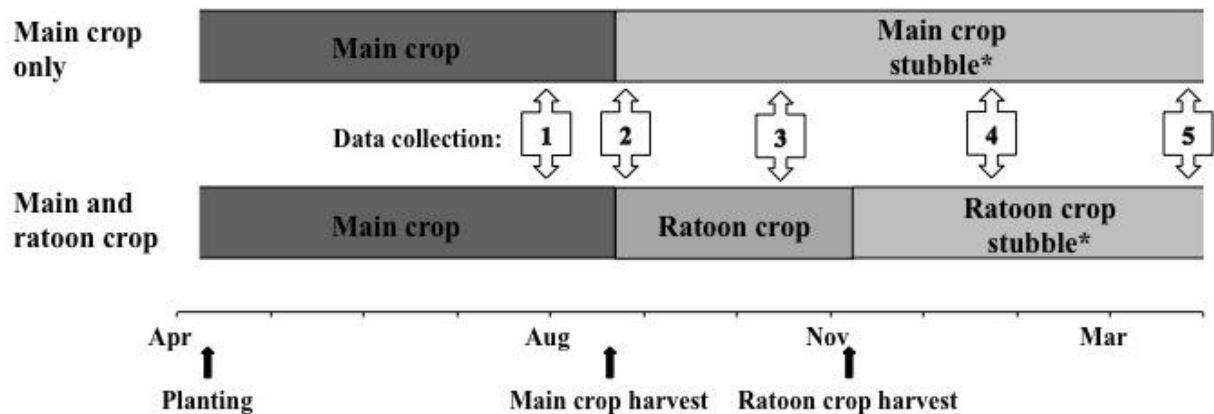


Fig. 8.1. Schematic representation of field experiments assessing stem borer infestations in rice managed to produce only a main crop and in rice managed to produce a main and ratoon crop, Ganado, Texas, 2007-2009. Data collection 1, 2, 3, 4, and 5 correspond to pre-main crop harvest, post-main crop harvest, October, January, and March samplings, respectively. * Main crop stubble and ratoon crop stubble refer to rice material remaining after main crop and ratoon crop harvest, respectively, including stubble and regrowth from the stubble

8.2.5. Data Analyses

Data from experiments initiated in 2007 and 2008 were analyzed separately because of differences in *D. saccharalis* and *E. loftini* relative densities, and post-main crop harvest experimental plot layout. All statistical analyses used linear mixed models in Proc GLIMMIX (SAS Institute 2008). The Kenward-Roger adjustment for denominator degrees of freedom was

used in all models to correct for inexact F distributions (Proc GLIMMIX, SAS Institute 2008). Unless stated otherwise, least square means \pm estimated standard errors from the LSMEANS statement output are reported. When fixed effects were detected ($P < 0.05$), Tukey's HSD ($\alpha = 0.05$) was used to assist in the interpretation of observed patterns and differences in least square means (Proc GLIMMIX, SAS Institute 2008).

To test whether stem borer injury differed among the seven rows used for sampling in each plot, models with "row" as fixed effect and "strip", "plot(strip)", and "row*plot(strip)" as random effects compared injured tiller and whitehead counts recorded prior to main crop harvest. Linear regressions with whitehead and injured tiller counts as the response and explanatory variables, respectively, were also conducted. "Strip", "plot(strip)", and "row(plot strip)" were random effects.

The effect of harvest cutting height on stem borer infestations surviving main crop harvest (post-main crop harvest infestations) was tested using models with "harvest height" as fixed effect and "strip", "plot(harvest height strip)" as random effects. The effect of main crop harvest cutting height on subsequent ratoon yields was tested using comparable models missing the "plot(harvest height strip)" random effect.

For the experiment initiated in 2007, stem borer infestations in main crop only and main and ratoon crop rice in October, January, and March (late and post-growing season infestations) were compared with models including "ratoon", "date", and "ratoon*date" fixed effects. Random effects were "strip(ratoon)", "plot(strip ratoon)", "date*plot(strip ratoon)." The potential carry-over main crop harvest cutting height effect on late and post-growing season infestations was not included in these models. For the 2008 experiment, fixed effects were "ratoon", "date", "harvest

height”, and the two- and three-way interactions. Random effects were “strip(ratoon)”, “plot(strip ratoon harvest height)”, and “date*plot(strip ratoon harvest height).”

Stem borer infestations recorded at different locations measured relative to the base of the culm were also compared. For stem borers recovered prior to main crop harvest, models included “location” as fixed effect. “Strip” and “plot(strip)” were random effects. For stem borers recovered within days after main crop harvest, comparisons were conducted exclusively on immatures collected from plots harvested at the 40-cm cutting height. Models included “location” as fixed effect. “Strip”, “plot(strip)”, and “section(plot strip)” were random effects. For the 2007 experiment, October stem borer infestations in ratoon plots were compared. Models included “location”, “harvest height”, and the interaction as fixed effects. Random effects were “strip”, “plot(harvest height strip)”, and “section(plot harvest height strip).”

8.3. Results

8.3.1. Pre-Main Crop Harvest Stem Borer Infestations

In 2007, stem borers heavily injured rice with on average 235.1 ± 10.3 (SE) injured tillers/m² and 26.5 ± 1.9 (SE) whiteheads/m². A linear regression ($F = 172.36$; $df = 1, 410.4$; $P < 0.001$) predicted that for every 9.0 injured tillers, one whitehead would be expected. Differences in injured tiller densities were detected ($F = 2.31$; $df = 6, 110.8$; $P = 0.039$) among the seven experimental rows of each plot. Rows in position 7 exhibited 1.3-fold more injury than rows in position 5, but no other pattern was detected. Whiteheads ($F = 1.87$; $df = 6, 474$; $P = 0.083$) showed a comparable distribution within plots. During plant dissection, 323 stem borers (99.1% *D. saccharalis*) were recovered (Table 8.1). Thirty-one percent of all dissected tillers with whiteheads were infested with at least one stem borer. All larval sizes and pupae occurred (Table 8.1), but empty pupal cases were not observed. Forty percent of the *D. saccharalis* immatures

were found boring into rice culms. For these *D. saccharalis*, infestations recorded at three locations within the culm were different ($F = 12.23$; $df = 2, 46$; $P < 0.001$). Four point seven, 62.5, and 32.8% of the immatures were located near panicles, high, and low, respectively (Fig. 8.2).

Table 8.1. Composition of stem borer infestations in rice, Ganado, Texas, 2007-2009

Date	Year	<i>E. loftini</i> immatures					<i>D. saccharalis</i> immatures				
		% small	% medium	% large	% pupae	n ^a	% small	% medium	% large	% pupae	n ^a
July	2007	33.3	0.0	66.7	0.0	3	38.8	34.7	25.9	0.6	320
	2008	11.7	32.1	48.9	7.3	137	16.4	32.7	47.3	3.6	55
August	2007	0.0	28.4	62.9	8.6	116	0.0	7.9	56.9	35.2	826
	2008	3.2	17.6	54.5	24.8	222	0.0	20.0	43.3	36.7	30
October	2007	17.3	39.6	34.2	8.9	202	3.2	4.8	85.7	6.3	63
	2008	7.7	40.7	49.1	2.5	570	14.8	11.1	70.4	3.7	27
January	2008	4.0	20.0	61.3	14.7	75	0.0	0.0	100.0	0.0	8
	2009	13.5	42.5	37.8	6.2	259	0.0	9.1	90.9	0.0	11
March	2008	43.2	18.2	11.4	27.3	44	0.0	0.0	60.0	40.0	5
	2009	0.0	75.0	0.0	25.0	4	0.0	0.0	66.7	33.3	3

^aNumber of stem borers recovered during plant dissection

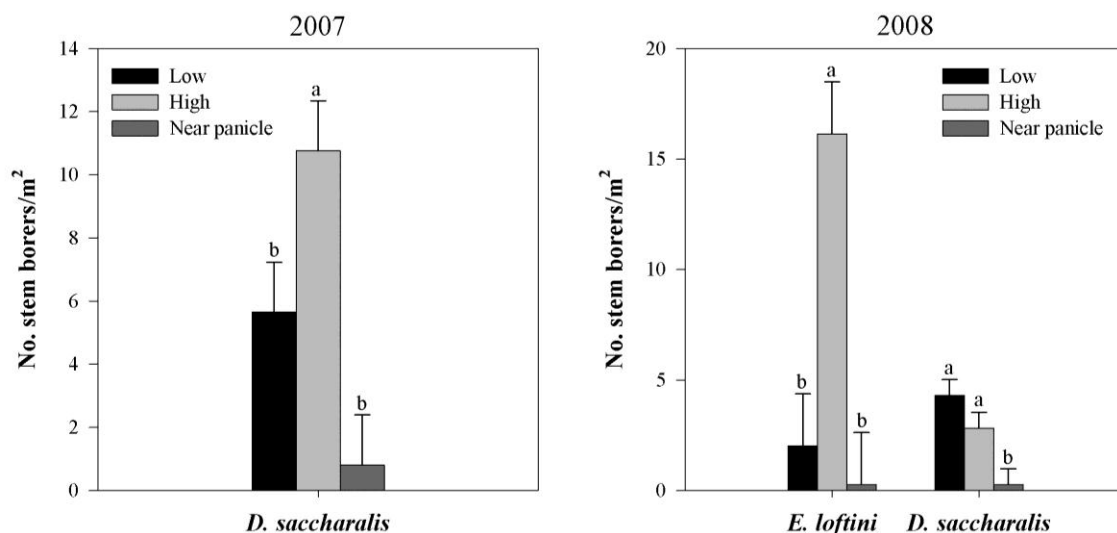


Fig. 8.2. Stem borer infestations by location in rice culms prior to main crop harvest in 2007 and 2008, Ganado, Texas. Data from 2007 only include *D. saccharalis* that had bored into culms whereas data from 2008 include stem borer feeding in leaf sheaths and within culms. For a stem borer species in a year, bars followed by the same letter are not different (Tukey's HSD, $\alpha = 0.05$)

In 2008, averages of 84.9 ± 4.2 (SE) injured tillers/m² and 12.3 ± 1.0 (SE) whiteheads/m² were observed. A linear regression ($F = 84.49$; $df = 1, 382.9$; $P < 0.001$) indicated that one whitehead would be expected for every 11.2 injured tillers. Differences in injured tiller and whitehead densities among plot rows were not detected ($F = 1.66$; $df = 6, 108.6$; $P = 0.138$ and $F = 1.69$; $df = 6, 138$; $P = 0.127$, respectively). *Eoreuma loftini* and *D. saccharalis* comprised 71.4% and 28.6% of the 192 stem borers recovered during plant dissection, respectively (Table 8.1). Thirty-nine percent of all dissected tillers with whiteheads were infested with at least one stem borer. All larval sizes and pupae were recovered (Table 8.1), as were three *E. loftini* empty pupal cases. Eighty-nine point one and 70.9% of the recovered *E. loftini* and *D. saccharalis*, respectively, had bored into culms, with the remaining larvae found feeding in leaf sheaths. *Eoreuma loftini* infestations differed among locations within the culm ($F = 17.94$; $df = 2, 64$; $P < 0.001$), with 1.5, 87.6, and 10.9% of the immatures located near panicles, high, and low, respectively (Fig. 8.2). For *D. saccharalis* ($F = 8.69$; $df = 2, 46$; $P = 0.001$), infestations located high and low within tillers were not different, but were greater than those occurring near panicles (Fig. 8.2).

8.3.2. Post-Main Crop Harvest Stem Borer Infestations

Main crop stubble height measured from three randomly selected tillers in each section of each plot was 38.3 ± 0.6 (SE) cm and 19.7 ± 0.6 (SE) cm in 2007 and 35.0 ± 0.5 (SE) cm and 18.9 ± 0.7 (SE) cm in 2008, respectively for the 40-cm and 20-cm harvest cutting heights. In August 2007, 942 stem borers (12.3% *E. loftini* and 87.7% *D. saccharalis*) were recovered, while 252 stem borers (88.1% *E. loftini* and 11.9% *D. saccharalis*) were recovered in August 2008 (Table 8.1). Compared to the 40-cm harvest cutting height, the 20-cm harvest cutting height was associated with lower *E. loftini* infestations in 2007 (81.2%; $F = 17.22$; $df = 1, 17$; $P = 0.001$)

and 2008 (70.2%; $F = 29.35$; $df = 1, 17$; $P < 0.001$) (Fig. 8.3). Differences in *D. saccharalis* infestations recovered from rice harvested at the 20- and 40-cm cutting heights were not detected ($F = 0.12$; $df = 1, 17$; $P = 0.738$ and $F = 1.70$; $df = 1, 70$; $P = 0.197$ in 2007 and 2008, respectively) (Fig. 8.3).

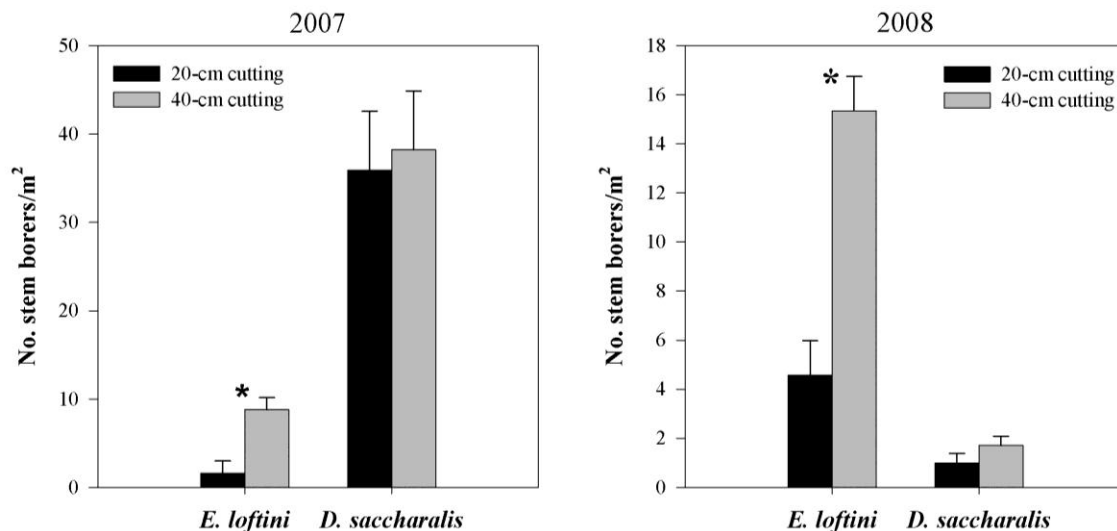


Fig. 8.3. Stem borer infestations in rice main crop stubble as affected by harvest cutting height in 2007 and 2008, Ganado, Texas. For a stem borer species in a year, * indicates that infestations differed ($P < 0.05$)

In rice harvested at the 40-cm cutting height, *E. loftini* infestations recorded at different locations within the culm were different ($F = 19.37$; $df = 2, 70$; $P < 0.001$ and $F = 38.99$; $df = 2, 94$; $P < 0.001$ in 2007 and 2008, respectively). *Eoreuma loftini* located high within culms represented 72.2 and 78.3% of the infestations recorded in rice plants in 2007 and 2008, respectively (Fig. 8.4). The location of 1.0 and 16.4% of the recovered *E. loftini* immatures, which escaped from rice culms and were found in the bags used to store plant samples, was undetermined in 2007 and 2008, respectively. Only two *E. loftini* empty pupal cases were collected from rice harvested at the 40-cm cutting height in 2007. However, 72 empty pupal cases were collected in 2008. Ninety point three, 9.7, and 0.0% of empty pupal cases collected in

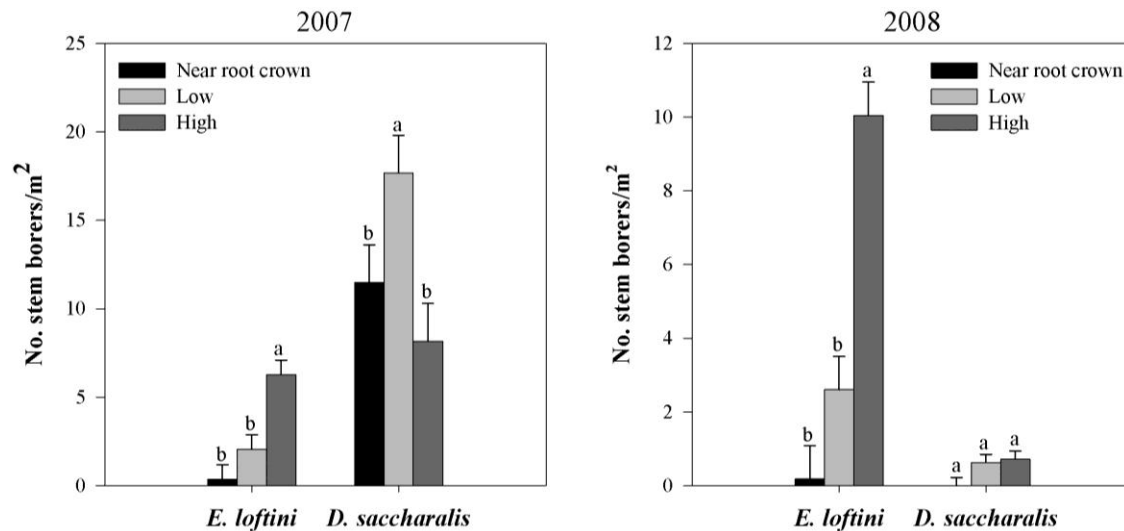


Fig. 8.4. Stem borer infestations by location in culms of rice previously harvested at a 40-cm cutting height in 2007 and 2008, Ganado, Texas. For a stem borer species in a year, bars followed by the same letter are not different (Tukey's HSD, $\alpha = 0.05$)

2008 were located high, low, and near root crown, respectively ($F = 35.95$; $df = 2, 105$; $P < 0.001$). For *D. saccharalis* occurring in rice harvested at the 40-cm cutting height in 2007, immatures located high, low, and near root crowns represented 21.9, 47.3, and 30.8%, respectively, of the infestations recorded in rice plants ($F = 13.82$; $df = 2, 70$; $P < 0.001$) (Fig. 8.4). The location of 2.3 % of the total recovered *D. saccharalis* immatures, which were found in bags used to store rice samples, was undetermined. One hundred and sixteen empty pupal cases were also collected from rice harvested at the 40-cm cutting height in 2007. Thirty-one point zero, 61.2, and 7.8% of empty pupal cases were located high, low, and near root crowns, respectively ($F = 16.73$; $df = 2, 70$; $P < 0.001$). In 2008, 53.3, 46.7, and 0.0% of the *D. saccharalis* immatures recorded in rice plants occurred high, low, and near root crowns, respectively ($F = 3.18$; $df = 2, 70$; $P = 0.048$) (Fig. 8.4). The location of 21.1% of the total recovered *D. saccharalis* immatures, which were found in bags used to store rice samples, was undetermined. Twenty-six empty *D. saccharalis* pupal cases were also collected. Empty pupal cases found low within culms represented 60.0% of the recorded pupal cases, and were more

abundant than those found near root crowns, but not different from those found high ($F = 4.07$; $df = 2, 94$; $P = 0.020$).

8.3.3. Late and Post-Growing Season Stem Borer Infestations

From late October 2007 to late March 2008, *E. loftini* infestations decreased by 77.0% ($F = 22.95$; $df = 2, 25.0$; $P < 0.001$) (Fig. 8.5). Infestations in main crop only and main and ratoon crop rice were not different ($F = 0.82$; $df = 1, 3.0$; $P = 0.432$). However, as shown by the ratoon \times date two-way interaction ($F = 17.61$; $df = 2, 25.0$; $P < 0.001$), the effect of producing a ratoon crop on *E. loftini* infestations changed with dates. In late October, main crop stubble was infested with 65.9% fewer *E. loftini* than was the ratoon crop (Fig. 8.5), while in mid-January and late March, differences between main crop stubble and ratoon crop stubble were not detected. All *E. loftini* larval sizes and pupae were observed between October and March (Table 8.1). In January, 45.3% of infestations were found feeding on live plant material whereas 41.3% occurred in dry stubble. Thirteen percent of the recovered stem borers escaped from rice culms after plant collection and were found in bags used for sample storage. In late March, 65.9% of the recovered *E. loftini* fed on live young rice growth [≤ 10 cm tall, 1-3 leaves, 20.3 ± 3.3 (SE) tillers/m²] arising from plots managed through the previous growing season, regardless of whether only a main crop or a main and ratoon crop had been produced. The remaining infestations were found in dry plant material. For *D. saccharalis*, infestations decreased by 92.5% between late October 2007 and late March 2008 ($F = 27.98$; $df = 2, 127.9$; $P < 0.001$) (Fig. 8.5). Infestation levels comparing main crop only and main and ratoon crop rice averaged across sampling dates were not different ($F = 1.20$; $df = 1, 16.7$; $P = 0.289$), but the ratoon \times date interaction ($F = 2.35$; $df = 2, 127.9$; $P = 0.099$) provided some evidence ($P \leq 0.1$) for increased *D. saccharalis* infestations in the ratoon crop in late October (Fig. 8.5). Whereas all larval sizes and pupae were observed in

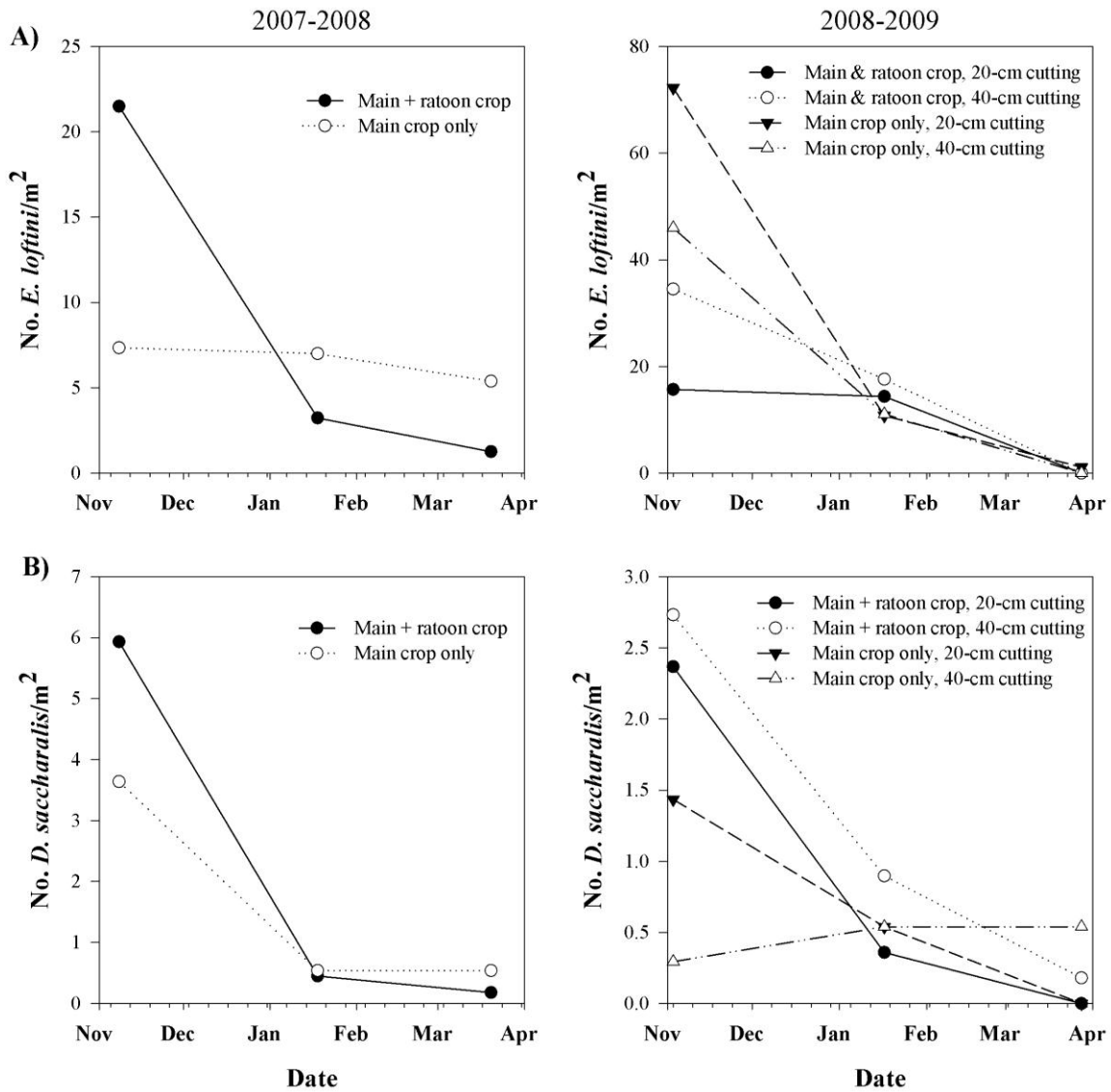


Fig. 8.5. Late and post-growing season (A) *E. loftini* and (B) *D. saccharalis* infestations in rice, Ganado, Texas, 2007-2008 and 2008-2009. The effect of main crop harvest cutting height was taken into account for infestations occurring in 2008-2009

October, only large larvae were observed in January, and large larvae and pupae were observed in March (Table 8.1). In January and March, all *D. saccharalis* immatures were found in dry plant material.

In the ratoon crop sampled in late October 2007, *E. loftini* immatures located high, low, and near root crowns represented 64.6, 34.0, and 1.4% of the infestations recorded in rice plants ($F = 28.08$; $df = 2, 46$; $P < 0.001$) (Fig. 8.6). As shown by the harvest cutting height effect ($F = 6.74$; $df = 1, 21.2$; $P = 0.017$) and the near significant harvest cutting height by location interaction ($F = 2.82$; $df = 2, 46$; $P = 0.070$), the proportion of *E. loftini* recorded high and low were different in rice plants previously harvested at the 40-cm cutting height, but not in those previously harvested at the 20-cm cutting height (Fig. 8.6). For *D. saccharalis*, 58.0 and 19.8% of immatures were located low and high, respectively, within culms ($F = 3.45$; $df = 2, 69$; $P = 0.037$) (Fig. 8.6). Main crop harvest cutting height did not affect *D. saccharalis* immature location in culms for the ratoon main crop stubble ($F = 0.02$; $df = 1, 69$; $P = 0.981$). The location of 0.6 and 2.2% of the total recovered *E. loftini* and *D. saccharalis* immatures, respectively, which were found in bags used to store rice samples, was undetermined.

From late October 2008 to late March 2009, *E. loftini* infestations decreased by 99.4% (Table 8.2, Fig. 8.5). In addition, infestations were less in main and ratoon crop rice than in main crop only rice (Table 8.2). However, this difference was associated with infestations that were 57.6% lower in the ratoon crop than in the main crop stubble in October, while differences between main crop stubble and ratoon crop stubble were not detected in mid-January and late March (Table 8.2, Fig. 8.5). An effect of reducing main crop harvest cutting height was not detected (Table 8.2). The two-way and three-way interactions ($P < 0.05$, Table 8.2) are not discussed in detail but provided evidence that main crop harvest cutting height slightly changed the ratoon

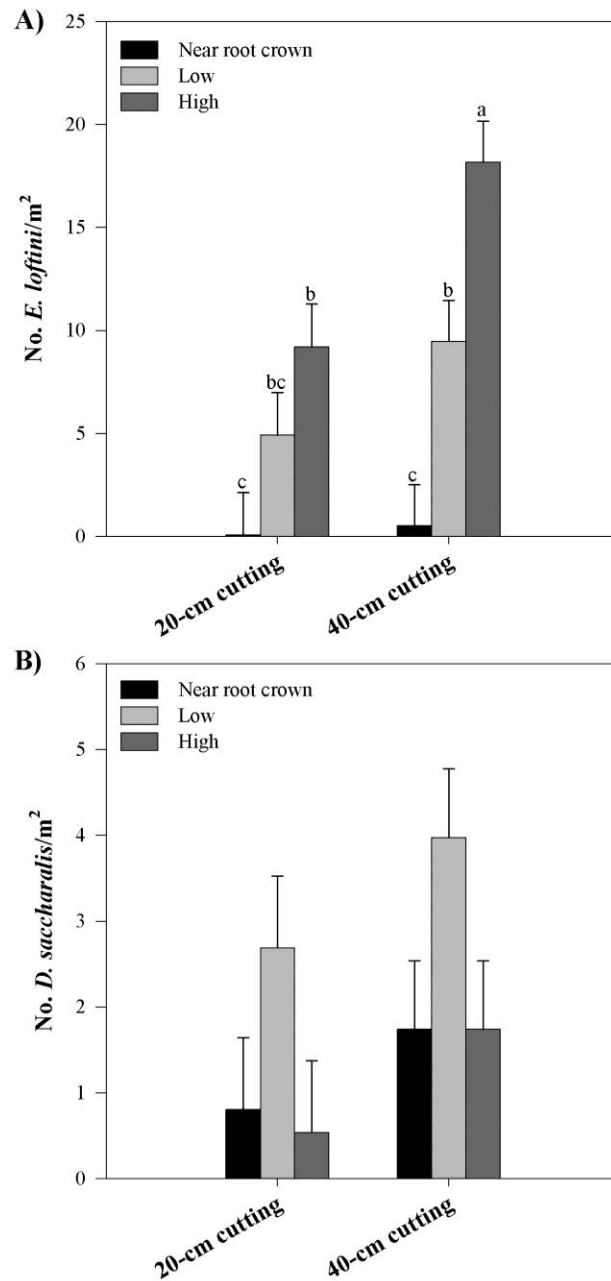


Fig. 8.6. (A) *E. loftini* and (B) *D. saccharalis* infestations by location in ratoon crop rice culms in late October 2007, Ganado, Texas. Bars followed by the same letter are not different (Tukey's HSD, $\alpha = 0.05$). Letters were not included when all bars were not different

effect and the ratoon by date interaction (Fig. 8.5). In rice previously harvested at the 20-cm cutting height, the ratoon crop was 78.3% less infested with *E. loftini* than the main crop stubble in October. However, differences in *E. loftini* infestations between the ratoon crop and the main crop stubble were not detected in rice previously harvested at the 40-cm cutting height (Fig. 8.5). In January and March, *E. loftini* infestations in ratoon and main crop stubble were not different regardless of main crop harvest cutting height (Fig. 8.5). All *E. loftini* larval sizes and pupae were observed in October and January (Table 8.1). In January, 66.8% of infestations were recovered from live plant material. In March, live *E. loftini* infestations were very low (Fig. 8.5) and live rice plant material was not available. Dead desiccated larvae [1.7 ± 0.4 (SE) larvae/m²] were observed in dead young rice tillers. For *D. saccharalis*, infestations decreased by 85.5% from late October 2008 to late March 2009, and did not differ between main crop only and main and ratoon crop rice (Table 8.2, Fig. 8.5). In January and March, all *D. saccharalis* immatures, mostly comprised of diapausing larvae, were found in dry dead stubble.

Table 8.2. Statistical comparisons for stem borer infestations in rice as affected by the production of a ratoon crop, main crop harvest cutting height, and sampling date, Ganado, Texas, October 2008-March 2009

Effect	<i>E. loftini</i>			<i>D. saccharalis</i>		
	<i>F</i>	df	<i>P</i> > <i>F</i>	<i>F</i>	df	<i>P</i> > <i>F</i>
Ratoon	14.98	1, 32.3	0.001	1.99	1, 156	0.161
Date	89.57	2, 31.9	< 0.001	5.52	2, 156	0.005
Ratoon × Date	21.65	2, 31.9	< 0.001	2.22	2, 156	0.112
Harvest height	0.11	1, 32.3	0.745	0.04	1, 156	0.833
Ratoon × Harvest height	10.39	1, 32.3	0.003	0.55	1, 156	0.458
Harvest height × Date	0.37	2, 31.9	0.692	0.36	2, 156	0.696
Ratoon × Harvest height × Date	7.48	2, 31.9	0.002	0.49	2, 156	0.613

8.4. Discussion

Our study showed that a substantial proportion of stem borers survives the rice main crop harvest. However, lowering harvest cutting height from a conventional 40 cm to 20 cm reduces

E. loftini infestations in the stubble. These findings are consistent with recommendations in Asia that encourage low harvest cutting heights to reduce *Chilo suppressalis* (Walker) and *Scirpophaga incertulas* (Walker) infestations (Litsinger 1994, Pathak and Khan 1994). However, recommendations for these Asiatic crambid stem borers emphasize that ground level harvest is most effective because *C. suppressalis* larvae are found 10-15 cm above ground whereas *S. incertulas* larvae occur lower in the culm (Pathak and Khan 1994).

The 20-cm harvest cutting height did not remove more *D. saccharalis* infestations than the 40-cm cutting harvest height. Tiller dissections showed that relatively more *E. loftini* immatures are located high in the plants (above 20 cm from the base of the culm) than are *D. saccharalis* larvae and pupae. Culm diameter, tissue toughness, as well as water and nutrient availability are chief factors affecting plant suitability (Patanakamjorn and Pathak 1967, Rodriguez-del-Bosque et al. 1995, Reay-Jones et al. 2007b, Showler et al. 2011), and therefore likely influence stem borer location in the plant. However, the difference between *E. loftini* and *D. saccharalis* distribution in rice plants is very likely associated with intrinsic differences in behavior between the two species. The results presented herein show that harvest cutting height differentially impacts the survival of *E. loftini* and *D. saccharalis*, due to where each species feed within the tillers, which can also influence yield losses (Lv et al. 2008, 2010).

The production of a ratoon crop is an opportunity to increase profitability from a single planting (Bollich and Turner 1988). Ratoon rice typically produces one fifth of the main crop yield (Texas A&M AgriLife 2010), with the only associated costs being nitrogen fertilization, irrigation, harvest, and grain drying (Bollich and Turner 1988). Thirty-eight and 20% of the total rice production area is ratooned in Texas and Louisiana, respectively (2000-2008 average, LSU AgCenter 2010a, Texas A&M AgriLife 2010). In addition to potential benefits relative to *E.*

loftini management, cutting the rice main crop at a lower than traditional height can increase ratoon yields (Jones 1993, Harrell et al. 2009). In our study, main crop harvest cutting height did not affect ratoon yield. Nevertheless, lowering main crop harvest cutting height, or harvesting at a conventional cutting height and subsequently mowing the stubble, slows harvest speed, can require additional mowing operations, and slows ratoon crop maturation (Harrell et al. 2009, McCauley et al. 2010). Rice producers should consider the agronomic potential of their ratoon crop and stem borer pest pressure before lowering main crop cutting height.

In late October, substantial stem borer infestations occur in the main crop stubble whether or not the stubble is managed for the production of a ratoon crop. At that time of the year, *E. loftini* was the most prevalent stem borer in our study, and Beuzelin et al. (2010b, Chapter 6) showed that adult populations are abundant. In the first year of our study, the ratoon crop had a greater infestation than did the unmanaged main crop stubble; however, data from the second year showed the opposite result. In unmanaged main crop stubble, poor tiller regrowth and large amounts of dead plant material were observed in October 2007. In October 2008, vigorous regrowth was observed. Although these differences in main crop stubble condition were not quantified, they may explain infestation differences between the two years. Both the main crop unmanaged stubble and the ratoon crop extend the availability of stem borer host plants during the fall and are not treated with insecticides under current production practices (McCauley et al. 2010). Ratoon crop phenology and associated suitability for stem borers depends on main crop harvest date, stubble height, fertilization, irrigation, and temperatures. Subsequent to comparable main crop production practices, unmanaged main crop stubble phenology will be more variable than that of the ratoon crop because of the lack of fertilization and irrigation. Thus, relative

differences in stem borer infestations between the ratoon crop and unmanaged main crop stubble are likely highly dependent on the phenological condition of the unmanaged stubble.

Rice main and ratoon crop stubble represent an overwintering habitat for *E. loftini* although infestations decrease during the winter. *Eoreuma loftini* larval and pupal infestations decrease because of overwintering mortality and adult eclosion occurring year-round (Rodriguez-del-Bosque et al. 1995, Chapter 6). In addition, in the ratoon crop and subsequent stubble, there is a potential for greater mortality associated with harvest in November. Nevertheless, a substantial density of *E. loftini* infests rice during the winter with as many as 13.4 larvae and pupae per m² in January 2009. By the end of the winter, infestations can remain high or sharply decrease (3.3 vs. 0.3 *E. loftini*/m² in March 2008 and 2009, respectively). As a comparison, grasses in non-crop areas adjacent to rice fields, which represent another important overwintering habitat in Texas rice agroecosystems, were found infested with 1.9 and 2.5 *E. loftini* per m² in mid-February 2008 and 2009, respectively (Chapter 6). In our study, January and February were drier and colder in 2008 than 2009 with respectively 126 vs. 8 mm cumulative rainfall and 4 vs. 9 d with temperatures below 0°C (Wilson et al. 2007). As a result, conditions for sustaining *E. loftini* populations and the availability of live host plant material were more favorable in 2008. April sampling in rice fields the previous year showed that any available live grass material, rice or weed, can serve as *E. loftini* host during the spring (Chapter 6). For *D. saccharalis*, dead large rice stubble hosts overwintering diapausing larvae.

In conclusion, our study shows that a low harvest cutting height can suppress late season *E. loftini* populations, and that rice stubble under favorable conditions represents an *E. loftini* and *D. saccharalis* overwintering habitat. In Louisiana, the rice industry may suffer annual economic losses as severe as \$45 million when *E. loftini* becomes established in the state. Management

approaches integrating insecticide applications, resistant cultivars, and cultural practices are recommended (Reay-Jones et al. 2008). Ultimately, the efficacy of stem borer management in rice has implications in sugarcane (*Saccharum* spp.), corn (*Zea mays* L.), and sorghum [*Sorghum bicolor* (L.) Moench], which are also attacked by stem borers and are grown adjacent to each other in certain areas of Texas and Louisiana. In addition, our study emphasizes how *E. loftini* and *D. saccharalis*, although both crambid stem borers of graminaceous crops, are not interchangeable pests. Our data suggest that relatively more *E. loftini* immatures are located high in rice plants while previous research shows differences in larval tunneling behavior in sugarcane (Legaspi et al. 1997a), oviposition substrate preference (Reay-Jones et al. 2008, Showler and Castro 2010b), and seasonal activity (Rodriguez-del-Bosque et al. 1995, Chapter 6). Successful stem borer IPM tactics must take into account these differences between *E. loftini* and *D. saccharalis*.

CHAPTER 9: SUMMARY

The stem borer *D. saccharalis* is the key insect pest of sugarcane in Louisiana. In addition, *D. saccharalis* severity has increased in rice-growing areas of Louisiana and Texas. *Eoreuma loftini* is a stem borer indigenous to Mexico and was first reported in 1980 in south Texas. This insect quickly became the most damaging pest of sugarcane in the Lower Rio Grande Valley of Texas. After expanding its range along the Gulf Coast, *E. loftini* has also become a problem for rice production in southeast Texas. *Eoreuma loftini* was detected in Louisiana for the first time in December 2008, representing a serious threat to the state's sugarcane and rice industries. In the spring of 2011, *E. loftini* has been consistently collected in pheromone traps throughout Calcasieu Parish. Economic projections of annual revenue losses have the potential to approach \$220 million for sugarcane and \$45 million for rice in Louisiana. Currently implemented stem borer management practices mainly target economically damaging populations that occur during the summer. However, at times of the year when stem borer populations do not contribute directly to economic injury, unmanaged populations may substantially impact subsequent pest numbers. Thus, the role of selected ecological factors and cultural practices anticipated to impact stem borers during the fall, winter, and spring were studied.

Twelve thousand to 16,000 ha of Louisiana sugarcane fields were flooded by salt water from the Hurricane Rita storm surge during the fall 2005. A four-treatment, 12-replication study comparing storm surge flooded and non-flooded plant and ratoon sugarcane fields was conducted the following year to assess *D. saccharalis* pest severity and soil-associated arthropod predator abundance. Even with a 2.4-fold increase in the average number of insecticide applications used for *D. saccharalis* management in flooded fields, growers still incurred higher injury. A 71% reduction in the predaceous *S. invicta* was associated with the storm surge, whereas no reduction

in abundance of other soil-associated arthropods was recorded. Arthropod diversity measured by the Shannon diversity index increased by 30% in sugarcane fields flooded by the storm surge. The increase in *D. saccharalis* pest severity associated with the storm surge caused an estimated loss between \$1.9 and \$2.6 million to the Louisiana sugarcane industry for the 2006 production season. This study showed that Hurricane Rita disrupted the naturally occurring *D. saccharalis* predaceous complex during the fall to a level requiring additional insecticide applications and causing economic losses in the subsequent growing season.

Two field experiments were conducted in Louisiana to determine the effects of four planting dates (early August, early September, early October, mid-November) on *D. saccharalis* infestations. Assessment of *D. saccharalis* infestations involved deadheart collections in the fall and spring. The number of deadhearts recorded in November of both years, showed that early August planting dates have greater *D. saccharalis* infestations and the potential to host major overwintering populations. However, differences among infestations were not recorded during the spring. This study showed that early plantings may increase *D. saccharalis* populations and affect inter-year pest dynamics in sugarcane.

Previous research reported that both stem borer species feed on a wide range of non-crop grasses. Two sentinel plant studies were conducted in southeast Texas to assess naturally occurring *E. loftini* and *D. saccharalis* infestations in five selected weed species. Amazon sprangletop, a common grass weed in rice fields, harbored stem borer infestations equivalent to or greater than those observed on rice, with as many as 78% of the plants infested with at least one larva. Johnsongrass and Vasey's grass, two ubiquitous perennial grasses, were also infested with levels lower than or equivalent to those observed on rice. These non-crop grasses supported complete stem borer larval development. On the other hand, both broadleaf signalgrass and

barnyardgrass, two common weeds in and near rice fields, proved to be poor stem borer host plants. These studies confirmed that non-crop hosts could play a key role in stem borer population build-up. However, the quantification of non-crop host presence and use has been limited, especially when crop hosts are absent or too young to sustain stem borer development. Thus, periodic sampling was conducted for 2 yr to estimate on-farm *E. loftini* and *D. saccharalis* seasonal infestations in non-crop hosts adjacent to rice fields. Three farms were selected in the Texas rice production area. On each farm, two transects were drawn along non-cultivated habitats near rice fields and sampled every 6-8 wk. While *D. saccharalis* densities were relatively low, *E. loftini* average densities ranged from 0.3 to 5.7 immatures per m² throughout the 2-yr period. Early annual grasses including ryegrass and brome were infested during the spring whereas the perennial johnsongrass and Vasey's grass were infested throughout the year. Johnsongrass was the most prevalent host (41-78% relative abundance), but Vasey's grass (13-40% relative abundance) harbored as much as 62% of the recovered *E. loftini* immatures (during the winter). Young rice in newly planted fields did not host stem borers prior to June. April sampling in fallow rice fields showed that any available live grass material, volunteer rice or weed, can serve as a host during the spring. This study showed that non-crop grasses are year-round sources of *E. loftini* in Texas rice agroecosystems and may increase pest populations. In addition, primary non-crop hosts were identified and their relative importance throughout the seasons was determined.

A greenhouse experiment was conducted to compare oviposition and larval development of *E. loftini* on rice and four primary non-crop hosts identified in on-farm periodic sampling. Accounting for plant availability, rice was more preferred for oviposition than non-crop hosts, and young plants were associated with lower preference coefficients than older plants. The most

preferred stages of johnsongrass and Vasey's grass were associated with preference coefficients 40 to 68% lower than those for the most preferred stages of rice. Brome received the lowest proportion of eggs and oviposition did not occur on ryegrass. *Eoreuma loftini* larval development duration in $^{\circ}\text{D} > T_0$ was fastest on rice (624 $^{\circ}\text{D}$) and slowest on Vasey's grass (992 $^{\circ}\text{D}$) and johnsongrass (1136 $^{\circ}\text{D}$). Larval development on brome and ryegrass was not different from that observed on rice. Development duration was not affected by plant stage, except on rice where larvae developed slower on younger plants. This study estimated parameters that can readily be integrated into population models to further the understanding of *E. loftini* dynamics on primary hosts of Gulf Coast rice agroecosystems.

Selected rice cultural practices anticipated to affect stem borer inter-year dynamics were also studied. Two field experiments in Texas assessed the effect of main crop harvest cutting height and the production of a ratoon crop on stem borer infestations from the late summer to the spring. Substantial infestations (> 5.6 stem borers/ m^2) remained in rice culms regardless of harvest cutting height (20 vs. 40 cm). However, the 20-cm cutting height reduced *E. loftini* infestations 70 to 81% whereas *D. saccharalis* infestations were not changed. Plant dissections showed that compared to *D. saccharalis* larvae and pupae, relatively more *E. loftini* immatures are located high in rice plants (> 20 cm from the base of the culm). In October, the ratoon crop was more infested with stem borers than the unmanaged main crop stubble during the first year of the study. The opposite was observed during the second year. Differences in unmanaged main crop stubble phenology between the two years likely caused these differences in infestation levels. During the post-growing season, infestations in main crop and ratoon crop stubble decreased over the winter. After favorable winter conditions, infestations in main crop and ratoon crop stubble were not different, attaining 3.3 *E. loftini*/ m^2 and 0.4 *D. saccharalis*/ m^2 by

March 2008. In March 2009, rice stubble harbored 0.3 *E. loftini*/m² and 0.2 *D. saccharalis*/m² regardless of whether only a main crop or a main and ratoon crop had been produced. This study showed that a lower rice harvest cutting height can suppress late season *E. loftini* populations. Furthermore, rice stubble under favorable conditions represents an overwintering habitat in addition to non-crop hosts.

This research project showed that predator disruptions, sugarcane planting dates, non-crop hosts, and rice stubble management impact stem borer populations when they are traditionally left unmanaged. Thus, the evaluation of a stem borer management strategy that targets infestations in late season sugarcane and rice, but also in non-crop hosts, is warranted. On-going studies are integrating results from this project into an analysis and forecast system to evaluate the efficacy of pest management tactics implemented at both field and regional levels. This whole systems approach is expected to facilitate the design of optimal tactics reducing stem borer infestations in Gulf Coast sugarcane and rice.

Because *D. saccharalis* may use non-crop hosts to a lesser extent than *E. loftini*, the determination of *D. saccharalis* preference and performance on primary crop and non-crop hosts would assist in quantifying the relative role of non-crop hosts in *D. saccharalis* population dynamics. Because the potential existence of host-associated sympatric stem borer strains may change IPM strategies, stem borer population genetic polymorphism may be studied. To help refine *E. loftini* and *D. saccharalis* population forecasts in space, future studies also may address stem borer dispersal. Because predation suppresses *D. saccharalis* populations in Louisiana sugarcane, future studies may determine the impact of natural enemies on *E. loftini* populations in crops, but also in weedy non-crop areas, which can be a source of biodiversity enhancing natural enemies.

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APPENDIX A: LETTER OF PERMISSION FOR CHAPTER 3

From: Alan Kahan <akahan@entsoc.org>
Subject: **RE: Permission Request**
Date: April 14, 2011 5:55:23 AM CDT
To: "Beuzelin, Julien" <JBeuzelin@agcenter.lsu.edu>
▶ 1 Attachment, 12.6 KB

April 14, 2011

Julien Beuzelin
Ecology of Sugarcane & Rice Insects
Department of Entomology
Louisiana State University
404 Life Sciences Bldg
Baton Rouge, LA 70803

Dear Mr. Beuzelin,

The Entomological Society of America grants you permission to use the article cited below as a chapter in your Ph.D. dissertation for the Graduate School of Louisiana State University.

Beuzelin, J. M., T. E. Reagan, W. Akbar, J. W. Flanagan, H. J. Cormier, and D. C. Blouin. 2009. Impact of Hurricane Rita storm surge on sugarcane borer (Lepidoptera: Crambidae) management in Louisiana. *Journal of Economic Entomology* 102: 1054-1061.

In addition, the Entomological Society of America grants you permission to use the manuscript noted below, if accepted for publication, also as a chapter in your Ph.D. dissertation for the Graduate School of Louisiana State University.

Manuscript# EN-11-44 entitled "Beuzelin, J. M., A. Meszaros, T. E. Reagan, L. T. Wilson, M. O. Way, D. C. Blouin, and A. T. Showler. Seasonal infestations of two stem borers (Lepidoptera: Crambidae) in non-crop grasses of Gulf Coast rice agroecosystems," which is currently in review for publication in *Environmental Entomology*.

Please provide proper credit.

Best wishes,

Alan Kahan
Director of Communications & Publications
Entomological Society of America
10001 Derekwood Lane, Suite 100
Lanham, MD 20706-4876
Phone: 301-731-4535 ext. 3020
Fax: 301-731-4538
akahan@entsoc.org

APPENDIX B: LETTER OF PERMISSION FOR CHAPTER 4

From: Waldemar Klassen <editor.fl.aentsoc@gmail.com>
Subject: **Re: Permission Request**
Date: April 12, 2011 11:15:50 AM CDT
To: "Beuzelin, Julien" <JBeuzelin@agcenter.lsu.edu>
▶ 1 Attachment, 12.6 KB

Mr. Julien Beuzelin:

The purpose of this message of April 12, 2011 is to grant you explicit permission to include the refereed paper given below as a chapter of your PhD dissertation for the Graduate School of Louisiana State University:

Beuzelin, J. M., A. Meszaros, W. Akbar, and T. E. Reagan. Sugarcane planting date impact on fall and spring sugarcane borer (Lepidoptera: Crambidae) infestations. Florida Entomologist 94(2): 242-252.

Yours sincerely,

Waldemar Klassen, Editor
Florida Entomologist.

APPENDIX C: LETTER OF PERMISSION FOR CHAPTER 5

From: Mac Hogarth <mac.hogarth@bigpond.com>
Subject: **RE: Permission Request**
Date: April 13, 2011 12:46:42 AM CDT
To: "Beuzelin, Julien" <JBeuzelin@agcenter.lsu.edu>
▶ 1 Attachment, 12.6 KB

Dear Julien

As Editor of the International Society of Sugar Cane Technologists (ISSCT), I have much pleasure in granting permission to use the article cited below for your PhD dissertation.

Beuzelin, J.M., Reagan, T.E., Way, M.O., Meszaros, A., Akbar, W. and Wilson, L.T. (2010). Potential impact of Mexican rice borer non-crop hosts on sugarcane IPM, pp 806-814). In Proceedings, XXVII Congress of the International Society of Sugar Cane Technologists, March 7-11, Veracruz, Mexico.

Please acknowledge that the paper was first presented at an ISSCT conference.

Best wishes

Mac

Mac Hogarth
Editor, ISSCT
email: mac.hogarth@bigpond.com
Phone: +617 3378 7868
Mobile: +61418741015
Address: PO Box 611, Indooroopilly 4068
Queensland, Australia.

APPENDIX D: SELECTED SAS PROGRAMS FOR CHAPTER 3

Soil-associated arthropod abundance

```
dm 'log;clear;output;clear';
Title1 'Soil-associated arthropod abundance';
data data;
input Flood$ Crop$ Area$ fireAnts Spiders Earwigs predBeetles miscBeetles Crickets Misc ;
cards;
/*data*/;
ods html file='F:\Stats\Storm Surge\Soil-Associated Arthropods_Output.html' style = minimal;

proc glimmix data=data;
Title2 'Fire_Ants';
class flood crop area;
model fireAnts = flood crop flood*crop / htype=3 ddfm=kr dist=poisson ;
random area(flood) ;
lsmeans flood crop flood*crop / diff cl ilink adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Storm Surge\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
quit;
```

Number of insecticide applications and proportion of bored internodes

```
dm 'output;clear;log;clear';
Title1 'Insecticides and bored internodes';
data data;
input Flood$ Crop$ Area$ Internodes Bored Insecticides ;
cards;
/*data*/;
ods html file='F:\Stats\Storm Surge\Insecticides and SCB internodes_Output.html' style =
minimal;

proc glimmix data=data;
Title2 'Insecticide applications';
class flood crop area;
model Insecticides = flood crop flood*crop / htype=3 ddfm=kr dist=poisson ;
random area(flood) ;
lsmeans flood crop flood*crop / diff cl ilink adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Storm Surge\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```

proc glimmix data=data;
Title2 'Proportion of bored internodes';
class Flood Crop Area ;
model Bored/Internodes = flood crop flood*crop / htype=3 ddfm=kr dist=binomial;
random area(flood) ;
lsmeans flood crop flood*crop / diff cl ilink adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Storm Surge\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
quit;

```


APPENDIX E: SELECTED SAS PROGRAMS FOR CHAPTER 4

Sugarcane availability estimates, fall 2006

```
dm'output;clear;log;clear';
Title1'Planting Dates / Sugarcane Availability Fall 2006';
data data1;
input Rep$ PD$ Cultivar$ CollectionDate1$ standCount avgHeight;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Fall Sugarcane Availability 2006.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'Stand counts ANOVA';
class Rep PD Cultivar CollectionDate1;
model standCount = PD Cultivar CollectionDate1
          PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
          PD*Cultivar*CollectionDate1 / htype=3 ddfm=kr dist=gaussian ;
random Rep Rep*PD Rep*PD*Cultivar;
random CollectionDate1 / subject = Rep*PD*Cultivar type=vc residual ;
lsmeans PD Cultivar CollectionDate1
          PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
          PD*Cultivar*CollectionDate1 / diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off; quit;
```

Sugarcane availability estimates, fall 2007

```
dm'output;clear;log;clear';
Title1'Planting Dates / Sugarcane Availability Fall 2007';
data data1;
input Rep$ PD$ Cultivar$ Row$ CollectionDate1$ standCount avgHeight;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Fall Sugarcane Availability 2007.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'stand counts ANOVA';
class Rep PD Cultivar Row CollectionDate1;
model standCount = PD Cultivar CollectionDate1
          PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
```

```

        PD*Cultivar*CollectionDate1/ htype=3 ddfm=kr dist=gaussian ;
random Rep Rep*PD Rep*PD*Cultivar Row(Rep*PD*Cultivar);
random CollectionDate1 / subject = Row(Rep*PD*Cultivar) type=vc residual;
lsmeans PD Cultivar CollectionDate1
        PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
        PD*Cultivar*CollectionDate1 / diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

```

ods graphics off; quit;

Deadheart densities, central row, fall 2006

```

dm'output;clear;log;clear';
Title1'Planting Dates / fall deadhearts central row 2006';
data data1;
input Rep$ PD$ Cultivar$ CollectionDate1$ DH;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Fall Central DH 2006.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'Fall Central DH 2006 ANOVA';
class Rep PD Cultivar CollectionDate1;
model DH = PD Cultivar CollectionDate1
        PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
        PD*Cultivar*CollectionDate1/ htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD Rep*PD*Cultivar;
random CollectionDate1 / subject = Rep*PD*Cultivar type=vc residual;
lsmeans PD Cultivar CollectionDate1
        PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
        PD*Cultivar*CollectionDate1 / diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off;
quit;

```

Deadheart densities, central rows, fall 2007

```
dm'output;clear;log;clear';
Title1'Planting Dates / fall deadhearts central rows 2007';
data data1;
input Rep$ PD$ Cultivar$ Row$ CollectionDate1$ DH;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Fall Central DH 2007.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'Fall Central DH 2007 ANOVA';
class Rep PD Cultivar Row CollectionDate1;
model DH = PD Cultivar CollectionDate1
          PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
          PD*Cultivar*CollectionDate1 / htype=3 ddfm=kr dist=gaussian ;
random Rep Rep*PD Rep*PD*Cultivar Row(Rep*PD*Cultivar);
random CollectionDate1 / subject = Row(Rep*PD*Cultivar) type=vc residual;
lsmeans PD Cultivar CollectionDate1
          PD*Cultivar PD*CollectionDate1 Cultivar*CollectionDate1
          PD*Cultivar*CollectionDate1 / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off; quit;
```

Deadheart and sugarcane borer densities, October 2006

```
dm'output;clear;log;clear';
Title1'Planting Dates / October 2006 Deadhearts and SCB';
data data1;
input Rep$ PD$ Cultivar$ DH totalSCB;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\October DH SCB 2006.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'October DH ANOVA';
class Rep PD Cultivar;
model DH = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff ;
```

```

ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'October total SCB ANOVA';
class Rep PD Cultivar;
model totalSCB = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'total SCB=f(DH) with Proc Glimmix';
class Rep PD Cultivar;
model totalSCB = DH / htype=3 ddfm=kr dist=gaussian s;
random Rep Rep*PD ;
run;

proc reg data=data1 all ;
Title2 'total SCB=f(DH) with Proc Reg';
model totalSCB = DH / influence;
plot totalSCB*DH;
plot residual.*predicted.;
plot residual.*NQQ.;
output out=two p=pred r=resid uclm= uclm lclm= lclm ucl=ucl lcl= lcl
      cookd=cook rstudent=rstudent dffits=dffits;
run;

ods graphics off; quit;

Deadheart and sugarcane borer densities, October 2006
dm'output;clear;log;clear';
Title1'Planting Dates / October 2007 Deadhearts and SCB';
data data1;
input Rep$ PD$ Cultivar$ Row$ DH totalSCB;
cards;
/*data*/;

```

```
ods html file='F:\Stats\Planting Dates\October DH SCB 2007.html' style = minimal;
ods graphics on;
```

```
proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'October DH ANOVA';
class Rep PD Cultivar;
model DH = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2' October total SCB ANOVA';
class Rep PD Cultivar;
model totalSCB = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'total SCB=f(DH) with Proc Glimmix';
class Rep PD Cultivar;
model totalSCB = DH / htype=3 ddfm=kr dist=gaussian s;
random Rep Rep*PD ;
run;
```

```
proc reg data=data1 all ;
Title2 'total SCB=f(DH) with Proc Reg';
model totalSCB = DH / influence;
plot totalSCB*DH;
plot residual.*predicted.;
plot residual.*NQQ.;
output out=two p=pred r=resid uclm= uclm lclm= lclm ucl=ucl lcl= lcl
      cookd=cook rstudent=rstudent dffits=dffits;
run;
```

```
ods graphics off;
quit;
```

Sugarcane availability, deadhearts, sugarcane borers, spring 2007

```
dm'output;clear;log;clear';
Title1'Planting Dates / Spring Data 2007';
data data1;
input Rep$ PD$ Cultivar$ StandCount DH SCBIII SCBIV SCBV Pupae;
totalSCB= SCBIII+SCBIV+SCBV+Pupae;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Spring 2007.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'Stand Counts ANOVA ';
class Rep PD Cultivar;
model StandCount = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'DH ANOVA ';
class Rep PD Cultivar;
model DH = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'totalSCB ANOVA ';
class Rep PD Cultivar;
model totalSCB = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD ;
lsmeans PD Cultivar PD*Cultivar / diff ;
```

```
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Sugarcane availability, deadhearts, sugarcane borers, spring 2008

```
dm'output;clear;log;clear';
Title1'Planting Dates / Spring Data 2008';
data data1;
input Rep$ PD$ Cultivar$ Row StandCount DH1 DH2 totalSCB;
DH= DH1+DH2;
cards;
/*data*/;
ods html file='F:\Stats\Planting Dates\Spring 2008.html' style = minimal;
ods graphics on;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'Stand Counts ANOVA ';
class Rep PD Cultivar;
model StandCount = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD Rep*PD*Cultivar;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'DH ANOVA';
class Rep PD Cultivar;
model DH = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD Rep*PD*Cultivar;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```

proc glimmix data=data1 plots=residualpanel(conditional) plots=boxplot(random);
Title2'totalSCB ANOVA';
class Rep PD Cultivar;
model totalSCB = PD Cultivar PD*Cultivar / htype=3 ddfm=kr dist=gaussian;
random Rep Rep*PD Rep*PD*Cultivar;
lsmeans PD Cultivar PD*Cultivar / diff ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Planting Dates\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off;
quit;

```


APPENDIX F: SELECTED SAS PROGRAMS FOR CHAPTER 5

Proportion of Mexican rice borers vs. sugarcane borers, 2006

```
dm 'log;clear;output;clear';
Title1'Sentinel Plants / Proportion MRB vs SCB 2006';
data counts1;
input trt$ rep$ MRB SCB allBorers ;
cards;
/*data*/;
ods html file='F:\Stats\Sentinel Plants\MRB vs SCB 2006.html' style = minimal;

proc glimmix data=counts1 ;
class trt rep;
model MRB/allBorers = trt / htype=3 ddfm=kr dist=binomial ;
random rep ;
random _residual_ ;
lsmeans trt / pdiff ilink ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Sentinel Plants\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
quit;
```

Proportion of plants infested with Mexican rice borers

```
dm 'log;clear;output;clear';
Title1'Sentinel Plants – Proportion plants infested';
data counts1;
input Trt$ Rep$ n MRB ;
cards;
/*data*/;
ods html file='F:\Stats\Sentinel Plants\Proportion Infested.html' style = minimal;

proc glimmix data=counts1 ;
Class trt rep;
model MRB/n = trt / htype=3 ddfm=kr dist=binomial ;
random rep ;
random _residual_ ;
lsmeans trt / pdiff ilink ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Sentinel Plants\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run; quit;
```

Number of Mexican rice borers per plant

```
dm 'log;clear;output;clear';
Title1'Sentinel Plants – No. MRB per plant';
data counts1;
input Trt$ Rep$ n MRB      ;
offset= log(n);
cards;
/*data*/;
ods html file='F:\Stats\Sentinel Plants\No MRB per Plant.html' style = minimal;

proc glimmix data=counts1 ;
class trt rep;
model MRB = trt / htype=3 ddfm=kr dist=poisson offset=offset ;
random rep ;
random _residual_ ;
lsmeans trt / pdiff ilink ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Sentinel Plants\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
quit;
```

APPENDIX G: SELECTED SAS PROGRAMS FOR CHAPTER 6

Mexican rice borer densities

```
dm'output;clear;log;clear';
title1'Transects- Mexican rice borer densities';
data data;
input Yr$ Dte$ Farm$ Transect$ Zone$ Quadrat$ QuadratSmallMRB QuadratMediumMRB
QuadratLargeMRB QuadratPupaeMRB QuadratEpupaeMRB QuadratMRB;
cards;
/*data*/;
ods html file='F:\Stats\Transects\Densities_MRB.html' style = minimal;
ods graphics on;

proc sort;
by Dte Yr Farm Transect Zone Quadrat;
run;
proc means;
var QuadratMRB;
by Dte Yr;
run;

proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'MRB = Year Date';
class Yr Dte Farm Transect Zone Quadrat;
model QuadratMRB = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Yr*Farm) Transect*Dte(Yr*Farm) Zone(Transect*Dte
Yr*Farm) ;
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off; quit;
```

Multivariate analysis, plant relative abundance

```
dm'output;clear;log;clear';
Title1'Transects- Grass description GLM analyses - 12 plants';
data data;
input Yr$ Dte$ Farm$ Transect$ Zone$ Quadrat$
    PercentJg CountJg    PercentVg CountVg PercentRg CountRg    PercentBr CountBr
    PercentCg CountCg    PercentAb CountAb PercentCb CountCb    PercentHd CountHd
    PercentHc CountHc    PercentJr CountJr PercentTg CountTg    PercentLt CountLt;
cards;
```

```

/*data*/;
ods html file='F:\Stats\Transects\GLM_Plant_Description.html' style = minimal;

proc glm data=data ;
Title2 '%grass = Year Date Year*Date';
class Yr Dte Farm Transect Zone Quadrat;
model PercentJg PercentVg PercentRg PercentBr PercentCg PercentAb
      PercentCb PercentHd PercentHc PercentJr PercentTg PercentLt
      = Yr Dte Yr*Dte
      Farm Farm*Yr Transect(Farm*Yr) Transect*Dte(Farm*Yr) Zone(Transect*Dte Yr*Farm)/
noui;
random Farm Farm*Yr Transect(Farm*Yr) Transect*Dte(Farm*Yr) Zone(Transect*Dte
Yr*Farm);
manova h=Yr          e=Farm*Yr          / printh printe htype=3 etype=3;
manova h=Dte Yr*Dte e=Transect*Dte(Farm*Yr) / printh printe htype=3 etype=3;
run;

proc glm data=data ;
Title2 'count grass = Year Date Year*Date';
class Yr Dte Farm Transect Zone Quadrat;
model CountJg CountVg CountRg CountBr CountCg CountAb
      CountCb CountHd CountHc CountJr CountTg CountLt
      = Yr Dte Yr*Dte
      Farm Farm*Yr Transect(Farm*Yr) Transect*Dte(Farm*Yr) Zone(Transect*Dte Yr*Farm)/
noui;
random Farm Farm*Yr Transect(Farm*Yr) Transect*Dte(Farm*Yr) Zone(Transect*Dte
Yr*Farm);
manova h=Yr          e=Farm*Yr          / printh printe htype=3 etype=3;
manova h=Dte Yr*Dte e=Transect*Dte(Farm*Yr) / printh printe htype=3 etype=3;
run;
quit;

```

Univariate analysis, plant relative abundance

```

dm'output;clear;log;clear';
Title1'Transects- Johnsongrass univariate analyses';
data data;
input Yr$ Dte$ Farm$ Transect$ Zone$ Quadrat$ Plant$ Percent Count V F M S D Size Diam
MaxSize MaxDiam;
cards;
/*data*/;
ods html file ='F:\Stats\Transects\Johnsongrass.html' style = minimal;

Proc sort;
by Dte Yr Farm Transect Zone Quadrat;
run;
proc means;

```

```

var Percent Count;
by Dte Yr;
run;
proc means;
var Size Diam MaxSize MaxDiam;
by Dte ;
run;
proc means;
var V F M S D;
by Dte ;
run;

proc glimmix data=data;
Title2 '% abundance = Year Date ';
class Yr Dte Farm Transect Zone Quadrat;
model Percent = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Yr*Farm) Transect*Dte(Yr*Farm) Zone(Transect*Dte
Yr*Farm) ;
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data;
Title2 'count = Year Date ';
class Yr Dte Farm Transect Zone Quadrat;
model Count = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Yr*Farm) Transect*Dte(Yr*Farm) Zone(Transect*Dte
Yr*Farm) ;
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data;
Title2 'size = Date ';
class Yr Dte Farm Transect Zone Quadrat;
model Size = Dte / htype=3 ddfm=kr ;
random Farm Transect(Farm) Transect*Dte(Farm) Zone(Transect*Dte Farm) ;
lsmeans Dte / diff adjust=tukey;

```

```

ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data;
Title2 'diam = Date ';
class Yr Dte Farm Transect Zone Quadrat;
model Diam = Dte / htype=3 ddfm=kr ;
random Farm Transect(Farm) Transect*Dte(Farm) Zone(Transect*Dte Farm);
lsmeans Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
quit;

```

Multivariate analysis, percent Mexican rice borers recovered in graminoids

```

dm'output;clear;log;clear';
Title1'Transects- % MRB in plants GLM analyses - 6 plants';
data data;
input Yr$ Dte$ Farm$ Transect$
      pMRBjg MRBvg pMRBrg pMRBbr pMRBcg pMRBab;
cards;
/*data*/;
ods html file='F:\Stats\Transects\GLM_Borers.html' style = minimal;

proc glm data=data ;
Title2 '% MRB in grass = Year Date Year*Date';
class Yr Dte Farm Transect ;
model pMRBjg MRBvg pMRBrg pMRBbr pMRBcg pMRBab
      = Yr Dte Yr*Dte
      Farm Farm*Yr Transect(Farm*Yr) / nouni;
random Farm Farm*Yr Transect(Farm*Yr) ;
manova h=Yr e=Farm*Yr / printh printe htype=3 etype=3;
manova h=Dte Yr*Dte / printh printe htype=3 etype=3;
run; quit;

```

Univariate analysis, percent Mexican rice borers recovered in a single graminoid

```

dm'output;clear;log;clear';
Title1'Transects- Proportion borers in Johnsongrass univariate analyses';
data data;

```

```

input Yr$ Dte$ Farm$ Transect$ Plant$
      transectHostMRB transectTotalMRB transectHostSCB transectTotalSCB
      percentHost percentMRBHost percMRBpercHost percentSCBHost percSCBpercHost;
cards;
/*data*/;
ods html file ='F:\Stats\Transects\Borers_johnsongrass.html' style = minimal;

Proc sort;
by Dte Yr Farm Transect ;
run;
proc means;
var percentHost;
by Dte Yr;
run;
proc means;
var transectHostMRB transectTotalMRB;
run;
proc means;
var percentMRBHost percMRBpercHost;
by Dte Yr;
run;

proc glimmix data=data;
Title2 '% MRB in Plant = Year Date ';
class Yr Dte Farm Transect;
model percentMRBHost = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Farm*Yr);
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

proc glimmix data=data;
Title2 '%MRB per %Plant = Year Date ';
class Yr Dte Farm Transect;
model percMRBpercHost = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Farm*Yr);
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes); quit;

```

Adult stem borer trapping

```
dm'output;clear;log;clear';
Title1 'Transects- Moth trapping';
data data;
input Yr$ Dte$ Farm$ Transect$ samplingDays MRB SCB MRB_Days SCB_Days;
cards;
/*data*/;
ods html file ='F:\Stats\Transects\Trap_catches.html' style = minimal;
ods graphics on;
```

```
Proc sort;
by Dte Yr Farm Transect ;
run;
proc means;
var samplingDays MRB SCB MRB_Days SCB_Days;
by Dte;
run;
proc means;
var samplingDays MRB SCB MRB_Days SCB_Days;
by Dte Yr;
run;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'MRB_days = Year Date';
class Yr Dte Farm Transect;
model MRB_Days = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Farm*Yr);
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'SCB_days = Year Date';
class Yr Dte Farm Transect;
model SCB_Days = Yr Dte Yr*Dte / htype=3 ddfm=kr ;
random Farm Farm*Yr Transect(Farm*Yr);
lsmeans Yr Dte Yr*Dte / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Transects\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes); run; ods graphics off; quit;
```


APPENDIX H: SELECTED SAS PROGRAMS FOR CHAPTER 7

Plant characteristics

```
dm 'log;clear;';
options nodate nocenter pageno=1 ls=78 ps=55;
title1 'Greenhouse Experiment 2009- Plant Characteristics';
data data; /*data are sorted by cage, grass, stage*/
input Grass$ Stage$ Trt$ Cage$ Characteristic;
cards;
/*data*/;
ods html file='F:\Stats\Greenhouse\Plant Characteristics.html' style = minimal;
ods graphics on;

proc mixed data = data plots=residualpanel(conditional) plots=boxplot(random);
title3 '1. Characteristic = plantSpecies [cage is random effects, equal variances]';
class Cage Trt ;
model Characteristic = Trt / htype=3 ;
random Cage ;
contrast 'Weeds vs Rice'      Trt 3 3 3 3 3 3 -10 -10 -10 3 3 3;
contrast 'Perennials vs Rice' Trt 0 0 1 1 1 0 0 -2 -2 -2 1 1 1;
contrast 'Annuals vs Rice'    Trt 3 3 0 0 0 3 3 -4 -4 -4 0 0 0;
contrast 'Perennials vs Annuals' Trt 3 3 -2 -2 -2 3 3 0 0 0 -2 -2 -2;
contrast 'B vs Rice'          Trt 6 6 0 0 0 0 0 -4 -4 -4 0 0 0;
contrast 'JG vs Rice'         Trt 0 0 1 1 1 0 0 -1 -1 -1 0 0 0;
contrast 'L vs Rice'          Trt 0 0 0 0 0 6 6 -4 -4 -4 0 0 0;
contrast 'VG vs Rice'         Trt 0 0 0 0 0 0 0 -1 -1 -1 1 1 1;
contrast 'JG vs VG'           Trt 0 0 1 1 1 0 0 0 0 0 -1 -1 -1;
contrast 'JG vs B'            Trt 6 6 -4 -4 -4 0 0 0 0 0 0 0 0;
contrast 'JG vs L'            Trt 0 0 4 4 4 -6 -6 0 0 0 0 0 0;
contrast 'VG vs B'            Trt 6 6 0 0 0 0 0 0 0 0 -4 -4 -4;
contrast 'VG vs L'            Trt 0 0 0 0 0 6 6 0 0 0 -4 -4 -4;
contrast 'B vs L'             Trt 1 1 0 0 0 -1 -1 0 0 0 0 0 0;
lsmeans Trt / pdiff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Greenhouse\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off; quit;
```

Size of oviposition events

```
dm 'log;clear;';
options nodate nocenter pageno=1 ls=78 ps=55;
title1 'Greenhouse Experiment 2009- Egg event size';
```

```

data data; /*data are sorted by cage, grass, stage*/
input Grass$ Stage$ Trt$ Cage$ eggEventID$ totalEggs;
cards;
/*data*/;
ods html file='F:\Stats\Greenhouse\Egg Mass Size.html' style = minimal;
ods graphics on;

proc mixed data = data plots=residualpanel(conditional) plots=boxplot(random);
title3 'Eggs per Egg Mass = plantSpecies stage [cage and plant are random effects, equal
variances]';
class Cage Trt ;
model totalEggs = Trt / htype=3 ;
random Cage Cage*Trt;
*
          B B J J J L L R R R V V V;
contrast 'Perennials vs Rice' Trt  0 3 3 -5 -5 -5 3 3 3;
contrast 'JG vs Rice' Trt  0 3 3 -2 -2 -2 0 0 0;
contrast 'VG vs Rice' Trt  0 0 0 -1 -1 -1 1 1 1;
contrast 'JG vs VG' Trt  0 3 3 0 0 0 -2 -2 -2;
lsmeans Trt/ pdiff adjust=tukey alpha=0.1 ;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Greenhouse\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.1,sort=yes);
run;

ods graphics off; quit;

```

Larval development duration

```

dm 'log;clear;';
options nodate nocenter pageno=1 ls=78 ps=55;
title1 'Greenhouse Experiment 2009- Development duration in degree-days';
data data; /*data are sorted by cage, grass, stage*/
input Grass$ Stage$ Trt$ Cage$ Female$ Duration;
cards;
/*data*/;
ods html file='F:\Stats\Greenhouse\Larval Duration.html' style = minimal;
ods graphics on;

proc mixed data = data plots=residualpanel(conditional) plots=boxplot(random);
title3 'Development Duration= plantSpecies stage sex [Cage and plant are random effects, equal
variances, no KR]';
class Cage Trt Female;
model Duration = Trt Female Trt*Female / htype=3 ;
random Cage Cage*Trt;
contrast 'Weeds vs Rice' Trt 3 3 3 3 3 3 3 -10 -10 -10 3 3 3;

```

```

contrast 'Perennials vs Rice'    Trt 0 0 1 1 1 0 0 -2 -2 -2 1 1 1;
contrast 'Annuals vs Rice'      Trt 3 3 0 0 0 3 3 -4 -4 -4 0 0 0;
contrast 'Perennials vs Annuals' Trt 3 3 -2 -2 -2 3 3 0 0 0 -2 -2 -2;
contrast 'B vs Rice'           Trt 6 6 0 0 0 0 0 -4 -4 -4 0 0 0;
contrast 'JG vs Rice'          Trt 0 0 1 1 1 0 0 -1 -1 -1 0 0 0;
contrast 'L vs Rice'           Trt 0 0 0 0 0 6 6 -4 -4 -4 0 0 0;
contrast 'VG vs Rice'          Trt 0 0 0 0 0 0 0 -1 -1 -1 1 1 1;
contrast 'JG vs VG'            Trt 0 0 1 1 1 0 0 0 0 0 -1 -1 -1;
contrast 'JG vs B'             Trt 6 6 -4 -4 -4 0 0 0 0 0 0 0 0;
contrast 'JG vs L'             Trt 0 0 4 4 4 -6 -6 0 0 0 0 0 0;
contrast 'VG vs B'             Trt 6 6 0 0 0 0 0 0 0 -4 -4 -4;
contrast 'VG vs L'            Trt 0 0 0 0 0 6 6 0 0 0 -4 -4 -4;
contrast 'B vs L'              Trt 1 1 0 0 0 -1 -1 0 0 0 0 0 0;
lsmeans Trt Female Trt*Female / pdiff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Greenhouse\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

/*
proc mixed data = data plots=residualpanel(conditional) plots=boxplot(random);
title3 'Development Duration= plantSpecies stage sex [Cage and plant are random effects,
Heterogenous Compound Symmetry]';
class Cage Trt Female;
model DD100Plant = Trt Female Trt*Female / htype=3 ;
random Trt / subject=Cage type=cs g;
lsmeans Trt Female Trt*Female / pdiff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Greenhouse Final Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
*/

ods graphics off; quit;

```

Correlations

```

dm 'log;clear;';
options nodate nocenter pageno=1 ls=78 ps=55;
title1 'Greenhouse Experiment 2009- Correlations';
data data;

```

```

input Host$ eggsFW eggsDW eggsCmMax eventsFW eventsDW eventsCmMax devtDuration
FW DW cmMaxOvip noTillersOvip noLeaves noDryLeaves DLperGL noTillersDiss
cmMaxDiss Diam;
cards;
BM 0.061 0.066 0.023 0.183 0.171 0.074 695.330 13.143 4.103 270.150
7.154 40.615 10.154 0.3326 10.308 312.150 2.345
BS 0.000 0.000 0.000 0.000 0.000 0.000 623.310 0.779 0.216 59.000 2.539
10.846 1.231 0.1291 9.539 297.850 2.087
JGL 0.366 0.321 0.458 0.489 0.378 0.601 1061.880 78.859 29.009 648.310
5.231 47.539 22.539 0.9529 5.846 704.080 3.775
JGM 0.244 0.252 0.306 0.333 0.296 0.431 1200.890 66.099 20.218 565.310
4.308 38.077 10.846 0.4079 6.000 728.920 4.076
JGS 0.000 0.000 0.000 0.000 0.000 0.000 1145.880 19.303 3.111 148.460
2.000 12.077 0.308 0.03448 2.154 265.380 5.098
LM 0.000 0.000 0.000 0.000 0.000 0.000 683.470 8.964 1.415 726.230
24.462 104.770 19.985 0.2446 27.077 1038.920 1.581
LS 0.000 0.000 0.000 0.000 0.000 0.000 657.130 1.296 0.185 134.000
8.077 26.000 0.779 0.03954 33.769 1212.920 1.477
RL 1.000 0.857 1.000 0.826 0.625 0.815 542.120 45.139 16.968 468.310
6.769 47.385 23.692 1.0369 8.231 523.920 4.025
RM 0.759 0.830 0.764 1.000 0.967 1.000 540.200 58.493 17.382 604.920
8.462 49.846 12.769 0.344 10.385 656.690 3.653
RS 0.538 1.000 0.215 0.597 1.000 0.238 788.400 8.827 1.571 243.230
4.615 20.769 2.154 0.1241 5.462 317.310 3.679
VGL 0.251 0.266 0.171 0.273 0.257 0.185 1020.230 60.479 18.196 903.000
11.539 61.692 25.692 0.7436 15.615 1174.770 3.704
VGM 0.316 0.391 0.323 0.474 0.521 0.479 973.360 102.840 26.757
1043.920 12.231 69.846 16.231 0.303 19.385 1549.620 3.569
VGS 0.147 0.269 0.110 0.333 0.526 0.234 982.860 19.223 3.536 271.310
6.769 26.308 3.692 0.1787 8.231 426.920 3.023;

```

```

proc template;
edit Base.Corr.StackedMatrix;
column (RowName RowLabel) (Matrix) * (Matrix2);
edit matrix;
cellstyle _val_ = -1.00 as {backgroundcolor=CXEEEEEE},
_val_ <= -0.75 as {backgroundcolor=red},
_val_ <= -0.50 as {backgroundcolor=yellow},
_val_ <= -0.25 as {backgroundcolor=cyan},
_val_ <= 0.25 as {backgroundcolor=white},
_val_ <= 0.50 as {backgroundcolor=cyan},
_val_ <= 0.75 as {backgroundcolor=yellow},
_val_ < 1.00 as {backgroundcolor=red},
_val_ = 1.00 as {backgroundcolor=CXEEEEEE};
end; run;
ods html body='F:\Stats\Greenhouse\Correlations.html' style=statistical;

```

```

ods graphics on;
ods listing close;

proc print data=data;

proc corr data=data noprob;
var eggsFW eggsDW eggsCmMax eventsFW eventsDW eventsCmMax devtDuration FW DW
cmMaxOvip noTillersOvip noLeaves noDryLeaves DLperGL noTillersDiss cmMaxDiss Diam ;
ods select PearsonCorr;
run;
proc corr data=data ;
var eggsFW eggsDW eggsCmMax eventsFW eventsDW eventsCmMax devtDuration FW DW
cmMaxOvip noTillersOvip noLeaves noDryLeaves DLperGL noTillersDiss cmMaxDiss Diam;
ods select PearsonCorr;
run;

ods listing;
proc template;
delete Base.Corr.StackedMatrix;
run;

ods graphics off; ods html close; quit;

```

Adjustment of p-values for multiple contrasts

```

dm'log;clear;';
Title1'P-value adjustment for multiple contrasts';
options nodate nonumber ps=55 ls=78;
data FW;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.7803
Perennials_Rice 0.0001
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0001
JG_Rice 0.0001
L_Rice0.0001
VG_Rice 0.0001
JG_VG 0.0005
JG_B 0.0001
JG_L 0.0001
VG_B 0.0001
VG_L 0.0001
B_L 0.386 ;

```

```

data DW;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0046
Perennials_Rice 0.0001
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0001
JG_Rice 0.0001
L_Rice0.0001
VG_Rice 0.0001
JG_VG 0.0232
JG_B 0.0001
JG_L 0.0001
VG_B 0.0001
VG_L 0.0001
B_L 0.049;

```

```

data cmMax;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0709
Perennials_Rice 0.0001
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0001
JG_Rice 0.5597
L_Rice0.7651
VG_Rice 0.0001
JG_VG 0.0001
JG_B 0.0001
JG_L 0.4122
VG_B 0.0001
VG_L 0.0001
B_L 0.0001;

```

```

data noTillersOvip;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0007
Perennials_Rice 0.4815
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0162
JG_Rice 0.0001
L_Rice0.0001

```

```

VG_Rice      0.0001
JG_VG        0.0001
JG_B  0.1712
JG_L  0.0001
VG_B  0.0001
VG_L  0.0001
B_L   0.0001;

```

```

data noLeaves;
input Contrast$ Raw_P;
datalines;
Weeds_Rice  0.0837
Perennials_Rice      0.245
Annuals_Rice 0.0347
Perennials_Annuals  0.2156
B_Rice0.0001
JG_Rice      0.0223
L_Rice0.0001
VG_Rice      0.0001
JG_VG        0.0001
JG_B  0.0447
JG_L  0.0001
VG_B  0.0001
VG_L  0.0002
B_L   0.0001;

```

```

data noDryLeaves;
input Contrast$ Raw_P;
datalines;
Weeds_Rice  0.0302
Perennials_Rice      0.6835
Annuals_Rice 0.0001
Perennials_Annuals  0.0001
B_Rice      0.0001
JG_Rice      0.0956
L_Rice0.0243
VG_Rice      0.0184
JG_VG        0.0001
JG_B  0.0001
JG_L  0.4389
VG_B  0.0001
VG_L  0.0001
B_L   0.0001;

```

```

data DL_GL;
input Contrast$ Raw_P;

```

```

datalines;
Weeds_Rice 0.0001
Perennials_Rice 0.033
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0001
JG_Rice 0.295
L_Rice0.0001
VG_Rice 0.0083
JG_VG 0.106
JG_B 0.0001
JG_L 0.0001
VG_B 0.0001
VG_L 0.0001
B_L 0.0392;

```

```

data diam;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0001
Perennials_Rice 0.3271
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.0001
JG_Rice 0.0001
L_Rice0.0001
VG_Rice 0.0008
JG_VG 0.0001
JG_B 0.0001
JG_L 0.0001
VG_B 0.0001
VG_L 0.0001
B_L 0.0001;

```

```

data noTillerDiss;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0001
Perennials_Rice 0.1413
Annuals_Rice 0.0001
Perennials_Annuals 0.0001
B_Rice0.1529
JG_Rice 0.0051
L_Rice0.0001
VG_Rice 0.0001
JG_VG 0.0001

```



```
JG_B 0.0001
JG_L 0.0001
VG_B 0.0009
VG_L 0.0001
B_L 0.0001;
```

```
data cmMaxDiss;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0001
Perennials_Rice 0.0001
Annuals_Rice 0.0001
Perennials_Annuals 0.0136
B_Rice0.0003
JG_Rice 0.1573
L_Rice0.0001
VG_Rice 0.0001
JG_VG 0.0001
JG_B 0.0001
JG_L 0.0001
VG_B 0.0001
VG_L 0.153
B_L 0.0001;
```

```
data larvalDD;
input Contrast$ Raw_P;
datalines;
Weeds_Rice 0.0001
Perennials_Rice 0.0001
Annuals_Rice 0.4375
Perennials_Annuals 0.0001
B_Rice0.5787
JG_Rice 0.0001
L_Rice0.5267
VG_Rice 0.0001
JG_VG 0.1267
JG_B 0.0001
JG_L 0.0001
VG_B 0.0007
VG_L 0.0021
B_L 0.9017;
```

```
ods html file = 'F:\Stats\Greenhouse Final Stats\Contrasts\Contrasts Characteristics Output.html'
style = minimal;
```

```
proc multtest inpvalues=FW bon holm ;  
title2 'FW';  
run;
```

```
proc multtest inpvalues=DW bon holm ;  
title2 'DW';  
run;
```

```
proc multtest inpvalues=cmMax bon holm ;  
title2 'cmMax';  
run;
```

```
proc multtest inpvalues=noTillersOvip bon holm ;  
title2 'noTillersOvip';  
run;
```

```
proc multtest inpvalues=noLeaves bon holm ;  
title2 'noLeaves';  
run;
```

```
proc multtest inpvalues=noDryLeaves bon holm ;  
title2 'noDryLeaves';  
run;
```

```
proc multtest inpvalues=DL_GL bon holm ;  
title2 'DL_GL';  
run;
```

```
proc multtest inpvalues=diam bon holm ;  
title2 'diam';  
run;
```

```
proc multtest inpvalues=noTillerDiss bon holm ;  
title2 'noTillerDiss';  
run;
```

```
proc multtest inpvalues=cmMaxDiss bon holm ;  
title2 'cmMaxDiss';  
run;
```

```
proc multtest inpvalues=larvalDD bon holm ;  
title2 'larvalDD';  
run;
```

APPENDIX I: SELECTED SAS PROGRAMS FOR CHAPTER 8

Pre-main harvest stem borer infestations as affected by position in each plot (row)

differed among the seven rows used for sampling in each plot

```
dm'output;clear;log;clear';
title1 'Harvest Height- Row Effect on injury and whiteheads';
data data;
input Strip$ PlotLabel$ Row$ Section$ Injury WH;
cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\Row Effect on Injury and WH.html' style = minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
title2 'Harvest Height- Row Effect on Injury';
class Strip PlotLabel Row Section ;
model Injury = Row / htype=3 ddfm=kr ;
random Strip PlotLabel(Strip) Row*PlotLabel(Strip) ;
lsmeans Row / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
title2 'Harvest Height- Row Effect on WH';
class Strip PlotLabel Row Section ;
model WH = Row / htype=3 ddfm=kr ;
random Strip PlotLabel(Strip) Row*PlotLabel(Strip) ;
lsmeans Row / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Linear regression estimating the number of whiteheads per tiller with stem borer injury

```
dm'output;clear;log;clear';
title1 'Harvest Height- PreMain Harvest WH = f(injury)';
data data;
input Strip$ PlotLabel$ Row$ Section$ Height$ Injury WH;
```

```
cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\PreMainHarvest Regressions_WH_Injury.html' style =
minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Row ;
model WH = Injury / htype=3 ddfm=kr s ;
random Strip PlotLabel(Strip) Row*PlotLabel(Strip) ;
run;
```

```
ods graphics off; quit;
```

Mexican rice borer position in rice culms prior to main crop harvest

```
dm'output;clear;log;clear';
title1 'Harvest Height- PreMain Harvest MRB Position';
data data;
input Year$ Block$ Strip$ PlotLabel$ Section$ Position$ MRB_CulmSheath;
cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\PreMainHarvest_Position_MRB.html' style = minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Position ;
model MRB_CulmSheath = Position / htype=3 ddfm=kr ;
random Strip PlotLabel(Strip) ;
lsmeans Position / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Post-main crop harvest Mexican rice borer infestations as affected by cutting height

```
dm'output;clear;log;clear';
title1 'Harvest Height- PostMain Harvest MRB';
data data;
input Strip$ PlotLabel$ Height$ Section$ MRBTotal;
cards;
/*data*/;
```

```
ods html file='F:\Stats\Harvest Height\PostMainHarvest_MRB.html' style = minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Section Height ;
model MRBTotal = Height / htype=3 ddfm=kr ;
random Strip PlotLabel(Height Strip);
lsmeans Height / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Mexican rice borer position in rice culms after main crop harvest

```
dm'output;clear;log;clear';
title1 'Harvest Height- PostMain Harvest MRB Position';
data data;
input Strip$ PlotLabel$ Section$ Position$ Live_MRB;
cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\PostMainHarvest_Position_MRB.html' style = minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Section Position ;
model Live_MRB = Position / htype=3 ddfm=kr ;
random Strip PlotLabel(Strip) Section(PlotLabel Strip);
lsmeans Position / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Mexican rice borer position in rice culms, October 2007

```
dm'output;clear;log;clear';
title1 'Harvest Height- PreRatoon Harvest MRB Position 2007';
data data;
input Strip$ PlotLabel$ Height$ Section$ Position$ Live_MRB;
```

```

cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\PreRatoonHarvest_Position_MRB_2007.html' style =
minimal;
ods graphics on;

proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Height Section Position ;
model Live_MRB = Height|Position / htype=3 ddfm=kr ;
random Strip PlotLabel(Height Strip) Section(PlotLabel Height Strip);
lsmeans Height|Position / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off; quit;

```

Mexican rice borer position in rice culms, October 2008

```

dm'output;clear;log;clear';
title1 'Harvest Height- PreRatoon Harvest MRB Position 2008';
data data;
input Strip$ PlotLabel$ Height$ Ratoon$ Section$ Position$ Live_MRB;
cards;
/*data*/;
ods html file='F:\Stats\Harvest Height\PreRatoonHarvest_Position_MRB_2008.html' style =
minimal;
ods graphics on;

proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
class Strip PlotLabel Height Ratoon Section Position ;
model Live_MRB = Ratoon|Height|Position / htype=3 ddfm=kr ;
random Strip(Ratoon) PlotLabel(Height Strip Ratoon) Section(PlotLabel Height Strip Ratoon);
lsmeans Ratoon|Height|Position / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;

ods graphics off;
quit;

```

Stem borer infestations from October to March, 2007-2008

```
dm'output;clear;log;clear';
Title1 'Harvest Height- MRB+SCB Ratoon Effect Yr 1';
data data;
input Year$ Strip$ PlotLabel$ Height$ Ratoon$ Section$ Date$ SCB_TOTAL MRB_TOTAL;
cards;
/*data*/;
ods html file ='F:\Stats\Harvest Height Stats\D345_Ratoon_Yr1_MRB_SCB.html' style =
minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'MRB Ratoon Effect Yr 1';
class Strip Ratoon PlotLabel Date;
model MRB_TOTAL = Ratoon Date Ratoon*Date / htype=3 ddfm=kr ;
random Strip(Ratoon) PlotLabel(Strip Ratoon);
lsmeans Ratoon Date Ratoon*Date / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'SCB Ratoon Effect Yr 1';
class Strip Ratoon PlotLabel Date;
model SCB_TOTAL = Ratoon Date Ratoon*Date / htype=3 ddfm=kr ;
random Strip(Ratoon) PlotLabel(Strip Ratoon);
lsmeans Ratoon Date Ratoon*Date / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
ods graphics off; quit;
```

Stem borer infestations from October to March, 2008-2009

```
dm'output;clear;log;clear';
Title1 'Harvest Height- MRB+SCB Ratoon Effect Yr 2';
data data;
input Year$ Strip$ PlotLabel$ Height$ Ratoon$ Section$ Date$ SCB_TOTAL MRB_TOTAL;
cards;
/*data*/;
```

```
ods html file ='F:\Stats\Harvest Height Stats\D345_Ratoon_Yr2_MRB_SCB.html' style =
minimal;
ods graphics on;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'Harvest Height-MRB Ratoon Effect Yr 2';
class Strip Ratoon Height PlotLabel Date;
model MRB_TOTAL = Ratoon|Height|Date / htype=3 ddfm=kr ;
random Strip(Ratoon) PlotLabel(Height Strip Ratoon);
lsmeans Ratoon|Height|Date / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
```

```
proc glimmix data=data plots=residualpanel(conditional) plots=boxplot(random);
Title2 'Harvest Height-SCB Ratoon Effect Yr 2';
class Strip Ratoon Height PlotLabel Date;
model SCB_TOTAL = Ratoon|Height|Date / htype=3 ddfm=kr ;
random Strip(Ratoon) PlotLabel(Height Strip Ratoon);
lsmeans Ratoon|Height|Date / diff adjust=tukey;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'F:\Stats\Harvest Height Stats\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
run;
ods graphics off;
quit;
```


VITA

Julien Marie Raoul Beuzelin was born and raised in Guadeloupe, French West Indies. After graduating from high school, he moved to France and attended the University of Rennes I where he received a Maîtrise (equivalent to a B.Sc.) in Cell Biology and Physiology in 2003. In his undergraduate experience, he studied nematodes, aphids, and pathogens attacking vegetable, melon, and carrot productions.

Julien attended the École Nationale Supérieure Agronomique de Rennes where he obtained his Diplôme d'Agronomie Approfondie (equivalent to a M.Sc.) in Crop Protection and Environment in 2005. Research for his Diplôme d'Agronomie Approfondie was conducted in Louisiana and Texas where he worked as an intern with Drs. T. E. Reagan (Louisiana State University) and L. T. Wilson (Texas A&M University). His research in Louisiana assessed on-farm efficacy of reduced-risk insecticides for sugarcane borer management in sugarcane. In Texas, he studied aspects of tri-trophic interactions between the sugarcane borer, a biological control agent, and rice.

In January 2006, Julien began his doctoral studies in the Department of Entomology at Louisiana State University with a minor in applied statistics. His dissertation research with Dr. T. E. Reagan has focused on the ecology and integrated pest management of stem borers in sugarcane and rice. He is currently completing the requirements for the degree of Doctor of Philosophy and plans to pursue his career in agricultural ecosystem research and extension.

Julien is married to Anna Mészáros.